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ZigBee-Wireless Mesh Networks for Building Automation and Control

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ABSTRACT: ZigBee is a wireless technology developed as an open global standard to address the unique needs of low-cost low-power wireless sensor networks. This standard takes full advantages of the IEEE 802.15.4 physical radio specification and operates in unlicensed bands worldwide at different frequencies. ZigBee-Wireless Mesh Networks (ZigBee-WMNs) are recognized as a cost-effective and flexible solution for building automation and control. They have the potential to unify the methods of data communication for sensors, actuators, appliances, and asset-tracking devices. They offer a means to build a reliable but affordable network backbone that supports battery-operated devices with a low data rate and a low duty cycle to facilitate building automation and control systems (BACs). This paper illustrates the possibilities and advantages of applying ZigBee-WMNs in BACs to benefit building occupants.

KEYWORDS: ZigBee, Wireless, BACs , Sensor Node , protocol, ZigBee-WMNs

I. INTRODUCTION

wireless sensor network can be defined as a network of sensor nodes that covers a wide area and provides environmental information about the monitored area through wireless communication protocols. It can be applied in many fields including healthcare, environmental monitoring, home automation, and the military. Wireless sensors have significant potential to allow for more cost-effective and efficient installation. Building automation and control systems (BACs) are characterized by a large number of sensors and controlled objects distributed in three-dimensional space. Figure 1 shows possible subsystems included in BACs: heating ventilation and air-conditioning (HVAC), lighting, electricity, hot water, fire, access,security/surveillance, and broadcast control systems. Wireless sensor connections eliminate the expenseassociated with hardwiring. In retrofit projects, an additional benefit includes less disruption to both occupants and the facility. Instead of placing sensors where they are easy to wire, sensors can be placed where they are actually needed to optimize building performance and to keep up with floor plan changes. Many articles have documented the use of wireless technology in buildings [3-8].

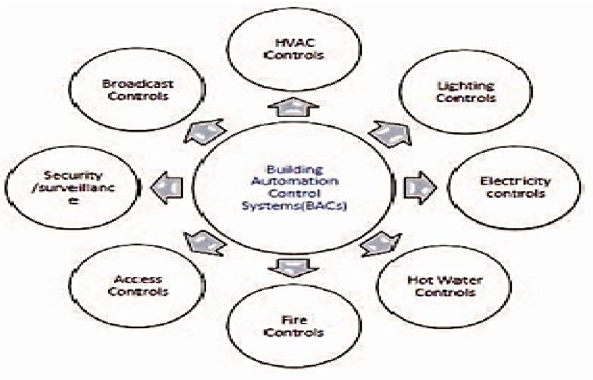

Figure 1 BACs elements

Wireless sensor networks open up new possibilities in BACs. Compared to wired network, a wireless sensor system in BACs would be more convenient and efficient, less dangerous and less costly. It can combine lighting, HVAC, security, safety systems and other monitoring networks into a single platform, reduce energy expense through optimized HVAC management, allocate utility cost equitably based on actual consumption, reconfigure lighting

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systems quickly to create adaptable workspaces and extend and upgrade building infrastructure with minimal effort. By installing a wireless mesh control network over a wide area, many organizations can reduce wasted lighting and heating expenditure by 50 percent [1].

ZigBee-Wireless Mesh Networks (ZigBee-WMNs) are self-configuring, self-healing and easy-to-maintain networks. Each device in the network contains a micro-controlled router that enables the network to be re-configured or expanded. If a device loses contact with an adjacent node, the self-healing properties of the network allow that node to find another node through which communications can occur. This trait helps to make the network reliable.

This paper discusses the possibilities and advantages of applying ZigBee-WMNs technology as a standard for BAC design.
The remainder of the paper is organized in II,III,IV,V & VI Section:

II. CHARACTERISTICS OF BUILDING AUTOMATION ANDCONTROL SYSTEMS

Intelligent building solutions increase comfort, energy efficiency, security, and occupant productivity in buildings. They employ a distributed control system that is a computerized, intelligent network of electronic devices to monitor and control the mechanical and other subsystems within a building. Well-designed BACs can be programmed to manage these controls, such as turning room lights off automatically when the room is unoccupied, turning on HVAC systems when the room temperature reaches a specified threshold, sending video streams from surveillance cameras to the security room every specified period, or logging access records when people pass through a door. To fulfill the above functions, BACs should have the following characteristics:

A. ROBUSTNESS

As more building functions are controlled electronically, it is imperative that they work in ways that users expect. Failure of the automation system is comparable in severity to a power loss, perhaps even rendering the building unusable until the problem is resolved. Therefore, robustness is important for BACs.

B. OPENNESS

Installing a building automation system is a long-term investment, and the prospect of being locked into a single vendor over decades can be unappealing to some operators. Open standards assure healthy competition and compatibility among multiple players, reducing the risk of obsolete or orphaned equipment.

C. STRAIGHTFORWARD COMMUNICATION

In most BACs, the relationship between sensors and controlled objects is straightforward. Most actuators are connected directly to control sensors. Therefore, static functional bindings are built up between devices and sensors when the system has been initially installed. A change detected by an occupancy sensor or wall switch is directly transferred to an appropriate load controller. Command and control functions are not dependant on third party application servers to mediate between sensors and loads for basic operations.

D. Security

BACs must be able to protect themselves from attack. The control system must be able to determine the trustworthiness of control requests and reject unauthorized commands.

E. ENERGY EFFICIENCY

A key motivation for installing building automation systems is to reduce the energy consumption of the building. BACs, however, represent a parasitic energy load, so equipment used in a wireless mesh network must use little power to reduce the total parasitic load since massive deployments of sensors is expected.

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F. COST

Sensor nodes are built using off-the-shelf components that are anticipated to be low in cost. The individual nodes may lack perfect reliability/quality, but redundancy achieved through large scale deployment can increase overall network reliability. To achieve this situation, the cost of the sensor nodes will need to drop. With mass production, a sensor node is projected to cost as low as a couple of dollars in the near future.

G. EASE OF USE AND MAINTAINS

Ideal BACs should be easy to operate and simple to maintain. Using energy-conservation techniques (putting nodes to sleep when they are idle), the nodes can last for months on a pair of AA batteries without the need for any line power. Furthermore, wireless sensor networks can be programmed to be self-configuring, enabling an ad-hoc mode of deployment. Therefore, deployment can be as simple as dropping nodes at certain locations in the area of interest.

III. EXISTING WIRELESS COMMUNICATION IN BUILDINGS

A. TRADITIONAL STANDARD FOR HOME NETWORKING

Of the few attempts to establish a standard for home networking that would control various home appliances, the X-10 protocol that was introduced in 1978 is one of the oldest [9]. It uses power line wiring to send and receive commands. A binary 1 is represented by a 1ms burst of a 120KHz signal at the zero-cross point and binary 0 by the absence of that 120KHz signal. These 1 millisecond bursts should actually be transmitted three times to coincide with the zero crossing points of all three phases in a three phase distribution system. Availability and simplicity have made X-10 the best-known home automation standard. It enables plug-and-play operation with any home appliance and does not require special knowledge to configure and operate a home network. Although the format of this code is simple, its slow speed, low reliability, and lack of security limit its usability. The effective data transfer rate is 60bps, a value that is too slow for any meaningful data communication between nodes. The protocol also suffers from heavy signal degradation in the power line. To power appliances, the X-10 transmission looks like noise and is subject to removal bythe power line filters. With the requirements of high reliability and security, the use of the X-10 network for BACs is out of date.

B. *UP-TO-DATE WIRELESS TECHNOLOGIES IN BUILDINGS*

In recent years, new wireless local area networks (WLANs) such as Wi-Fi [12] and wireless personal area networks (WPAN) such as Bluetooth [13] and ZigBee have become available. Table I shows the strengths and applications of these different systems. WiFi and Bluetooth technologies cannot satisfy the requirements for a home network or BAC. Devices in BACs need to have low power consumption, low cost, and simple operation. Table I demonstrates the large energy consumption associated with WiFi technology. Its current draw for an active data transmission is 400mA, which is more than 10 times larger than that of ZigBee technology. The differences also apply to standby mode; ZigBee only consumes 0.1µA, while WiFi and Bluetooth use 20mA and 0.2mA respectively. In home networks and BACs, most types of data circulated within a network of sensors and actuators are small packets that control devices or obtain data from them. The devices usually stay in deep-sleep mode and only send short bursts of data if a trigger event occurs. Unlike WiFi and BlueTooth, which are designed to transmit continuous data streams, ZigBee is designed for periodic data delivery. Considering that battery life and low cost are more important for BACs than high data rates, ZigBee is an appropriate technology for these applications. Typical battery life for WiFi devices would be approximately 0.5 to 5 days, and Bluetooth devices would need new batteries from 1-7 days. ZigBee devices, however, can last up to several months with a single set of batteries. The scalability of the entire network is also very important. On a home network, a WiFi network can be built to have a few dozen nodes to make sure all access points can communicate efficiently while the Bluetooth network can only contain several nodes. A ZigBee supported network, however, can have more than 64 000 nodes.

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IV. WHY ZIGBEE -WMNS FOR BACS

To meet the ever increasing requirements of BACs, ZigBee-WMNs are being considered to increase the capabilities of the systems. In this section, we highlight the most important, practical details that can address a useful metric for designs and applications of ZigBee-WMNs in BACs.

A. ZIGBEE

The ZigBee Alliance, an industry working group that promotes the ZigBee protocol [11], is developing standardized application software that uses the IEEE 802.15.4 wireless standard for the physical layer [14]. ZigBee-compliant products operate in unlicensed bands worldwide, including 2.4GHz (global), 902 to 928MHz (Americas), and 868MHz (Europe). Comparisons among these three bands are listed in Table II. The transmission distance is expected to range from 10 to 75m, depending on power output and environmental automation. ZigBee chips can be found in temperature, moisture, and vibration sensors, switches, and controllers. While there are many benefits to the use of ZigBee, there are still many concerns that have prevented a massive adoption of wireless sensor network in building applications. Main concerns from BACs designers, building tenants and occupants are system cost, security, reliability, battery life and management of sensors.

TABLE 1 COMPARISON OF WIFI, BLUETOOTH AND ZIGBEE [THEINDUSTRIAL WIRELESS BOOK, 2009]

	wifi	BlueTooth	ZigBee
Bandwidth	Up to 54Mbps	1Mbps	250kbps
Current Draw (Transmission)	400 mA	400 mA	30mA
Current Draw (standby	20mA	0.2mA	<0.1μA
Protocol stack Size (KB)	100	100	4-32
Stronghold	High data rate	Interoperability cable replacement	Long battery life, low cost
Transmission Range (meters)	1-100	1-10	1-100
Battery Life (days)	0.5 – 5	1-7	100-1000
Network Size(# of nodes)	32	7	>64,000
Application	Web, Email, Video	Cable Replacement	Monitoring & Control
Throughput (kb/s)	11,000	720	20 - 250

B. CHARACTERISTICS OF ZIGBEE-WIRELESS MESH NETWORKS FOR BACS

The architecture and floor plan of the building will often dictate how a wireless sensor network is deployed. ZigBee networks can be set up in both star and mesh topologies, but it is expected that the mesh configuration will be used in many commercial buildings to account for the varying floor plans. In such a configuration, it is desired that each node be located within signal range of at least two other nodes to form redundant paths for data routing. If the sensor density is not sufficient, an alternative way to accomplish this node density is to use low-cost repeaters whose only function is to fill in the mesh and provide more connections for the network. The network is self-forming and self-healing and provides the maximum flexibility for route selection.

1) Flexibility

There are two meanings of flexibility for BACs. First, sensors can be placed in nearly any location within the building. The second meaning refers to the flexibility of sensor node configuration. For location flexibility, building engineers are free to place nodes in the most critical monitoring locations instead of simply near available signal wires. This flexibility could greatly improve energy efficiency, reducing wasted lighting and heating expenditure by 50 percent in many cases [1]. Flexibility also exists when considering the configuration of the sensor network. Configuration can occur at any time and be readily changed as needs evolve. For example, a room entry switch or sensor can be

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reconfigured later to implement functions not envisioned when the sensor is initially installed.

2) Network scalability

BACs for larger residential or commercial buildings need to scale to larger geographic network coverage. According to [2], more than 68% of newly constructed commercial buildings after 1990 were larger than 464 m^2 of floor space. In year 1999, 16% of new construction involved buildings that were larger than 4000 m^2. Since the power levels of wireless devices are limited by regulatory agencies, a true mesh network with nodes spread over a large must be built to meet the building monitoring requirements. ZigBee-WMNs have the ability to deploy more than 64 000 nodes throughout a building. Thus, they are one of the best solutions for a wide spread and expandable BACs.

3) Network availability

ZigBee-WMNs have the functionality to control a variety of sensors placed throughout the building. The organization of these sensors needs to be well designed to optimize performance of the network. The structure of the ZigBee-WMN can allow for sensors to simply collect data and transmit to an associated actuator, can instruct a sensor to transmit its data through the network to a central computer, or can instruct a sensor node to both collect data and transmit data from other sensor nodes. These features can be used to optimize the performance of both the wireless sensor network and the building control system.

4) Easy to maintain

ZigBee-WMNs are easier to maintain than other wireless networks. Maintenance personnel can use a laptop or handheld diagnostic device to communicate and perform diagnostics, without running wires. This is a significant advantage in cases where controllers are inside storage tanks, on top of towers, or in other hard-to-reach locations. Installation cost savings are usually enough to justify wireless controllers. Instead of hiring wiring architects and teams of technicians, then phasing installation over a period of weeks or months, one person can walk around the building, placing controllers wherever needed.

V. ZIGBEE-WMNS IN CONNECTION WITH OTHER EXISTINGNETWORKS

It is hard to find networking technology that can fulfill all building requirements simultaneously. Different networks are available for building automation systems, such as EIB (European Installation Bus) or KNX (Konnex) [17], Local LON [16] and BACnet [18]. Often, heterogeneous technologies are combined into appropriate networking solutions. Since these networks are intended for wired BACs, deployment of wireless features as part of the BAC may involve connection between ZigBee-WMNs and other existing wired BACs.

A. ZIGBEE-WMNS WITH BACNET

BACnet is a popular open communication protocol for connecting components of building automation systems that was developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The standard specified both hardware connections and communication protocols. A challenge exists in determining how to deploy ZigBee-WMNs in existing BACnet systems. The inclusion of wireless devices can allow existing wired BACnet devices to be quickly upgraded to use ZigBee devices on the building control network. Once a ZigBee node finds and connects to its PAN (personal area network), it must find the subset of nodes that form its BACnet network. It does this in three ways: broadcast, multicast, or unicast call as listed in Table III.

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TABLE III COMPARISONS OF DIFFERENT CALL FUNCTIONS

	Broadcast	Multicast	Unicast
Sending Message	To entire PAN	To a group of nodes	To a predefined node
Receiving Message	Every node within the PAN	Group of node belonging to BACnet	A specific node
Pros	Programming is simple	Consuming less Bandwidth, Quickly rejected wrong messege	Conserving bandwidth
Cons	Consuming bandwidth forcing every mode on the PAN to read and interpret message	N/A	Time Consumption

The integrated BACnet and ZigBee network is fully configured after the commissioning process is complete. Data travels on the wireless network much the same as it would on a wired network. Neither ZigBee nor BACnetrestricts the size of messages. Both technologies can accommodate any size message by chopping it into packets. This ability is called segmentation in BACnet and fragmentation in ZigBee.

B. WMNS WITH TRADITIONAL COMPUTER NETWORKS

It is also conceivable that a wireless mesh network be integrated with a traditional computer network for building automation purposes. Interconnecting the WMN to general-purpose networks makes it easy to gain remote access to the automation network using existing Internet secure remote access protocols such as SSL (Secure Sockets Layer), IPsec (Internet Protocol Security) and VPN (virtual private network). Security is critical to prevent an attacker from hijacking the automation system for unwanted purposes.

Figure 2 shows a typical WMN consisting of sensor/control devices, wireless mesh routers, and access points linking the mesh network to the IP data network. WMNs consist of three device classes: endpoints, routers and Access Points. Endpoints are of limited functionality and are often battery powered. Endpoints are able to transmit or receive messages, but do not forward external messages to other endpoints. Full function devices have all the capability of Endpoints and can additionally act as routers that forward incoming messages to the ultimate destination. Access Points interconnect WMN devices to the local IP network. Access Points allow a browser on a PC to observe and control WMN devices.

Building owners have a list of issues to deal with today. They want to provide potential tenants the latest technologies. Especially for building owners of historically significant structures, they want to offer the same capabilities as new buildings but without destroying historical architecture. Lately, more and more building owners want to “go green” and use energy more efficiently [11]. BACs must meet a higher standard, and there is no room for controllers that are constantly going offline as network connections fade or break down. The ideal building automation network should be able to serve IEEE 802.11 devices and be scalable to support a number of devices deployed in buildings. Under such circumstances, heterogeneous technologies have to be combined into an appropriate networking solution, and ZigBee-WMNs have been shown to be seamlessly connected with other existing building networks.

To date, several companies have already realized the potential of WMNs in building automation design, And ZigBee-WMNs will be continue to be embedded in a wide range of products and applications across BACs. Many research topics, however, such as network security, scalability and battery lifetime issues are waiting to be addressed.

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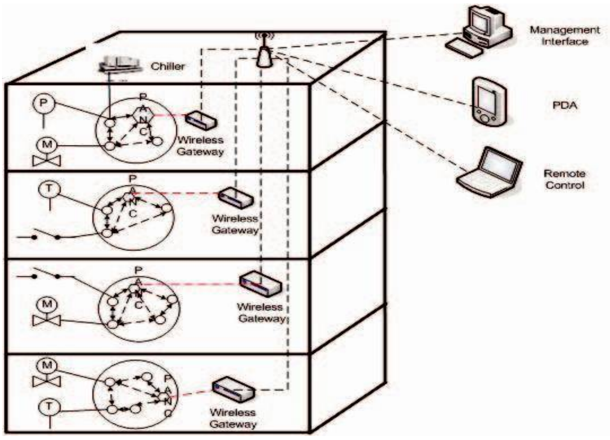

Figure 2 ZigBee-WMNs in connection with WiFi

VI. CONCLUSION

Based on protocol features implemented in IEEE 802.15.4, ZigBee has a bright future. BACs, however, is the biggest market for ZigBee-enabled devices. ON World predicts that global WSN products and services for the BACs will be worth $6 billion in 2012 [15]. ZigBee-WMNs are recognized as a cost-effective and flexible solution for building automation and control. They can be remarkably affordable and accessible. ZigBee-WMNs provide an ideal solution in harsh, dangerous, and difficult environments where devices are widely distributed. ZigBee-WMNs promise to make building automation as common as traditional computer networks. In a few years, the vision is that one will be able to go down to the local market and pick up sensors and controlled devices and quickly install and configure them.

Over the coming years, ZigBee-WMNs will become more dominant in commercial buildings. A number of features and benefits from ZigBee-WMNs will change the way people look and think about building construction, operation and maintenance. Deploying ZigBee-WMNs for process and automation networks can save time and money as there is no need to hardwire devices together. New developments offer redundancy, security and scalability which are crucial to process and factory automation networks.

TABLE II FREQUENCY ALLOCATIONS AND PHYSICAL LAYER IN IEEE 802.15.4 [ZIGBEE ALLIANCE, 2009]

PHY (MHz)		Spreading Parameters		Data Parameters		
	Frequency Band (MHz)	Chip rate (kchips/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868	868 – 868.6	300/400	BPSK**/ASK/O-QPSK*	20/100/250	20/12.5/62.5	Binary/20-bit DSSS*** /16-ary Orthogonal
915	902 – 928	600/1000/1600	BPSK**/ASK/O-QPSK*	40/250	40/50/62.5	Binary/5-bit DSSS*** /16-ary Orthogonal
2450	2400 – 2483.5	2000	O-QPSK*	250	62.5	16-ary Orthogonal

O-QPSK* (Offset Quadrature Phase Shift Keying) BPSK** (Binary Phase Shift Keying) DSSS*** (Direct Sequence Spread Spectrum)

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BIOGRAPHY

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