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A Study on the ZigBee Wireless Communication for IAQ Monitoring of Underground Subway Stations

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ABSTRACT

In this paper, the 424MHz ZigBee module, which uses a relatively lower frequency for wireless transmission and reception, is found to have a much higher data transfer rate than that of the 2.4GHz XBee-PRO in the presence of obstacles such as subway waiting rooms, platform-like stairs, complicated structures, and crowded passengers. This indicates that low frequency radio waves have better diffraction characteristics and thus better performance in face of obstacles. Therefore, it was found that low frequency Zigbee modules are advantageous in areas with complex structures such as subways.

KEYWORDS: *subway station, wireless communication, ZigBee module, XBee-PRO*

I. INTRODUCTION

The IAQ (Indoor Air Quality) has been recognized as a significant factor in the determination of the health and welfare of people [1]. The Korea Ministry of Environment (KMOE) enforced the IAQ act to control some pollutants, including PM_{10}, CO_2 in indoor environments. The IAQ is critical not only in buildings, but also in underground areas and public transportation systems. Much effort has been made for the improvement of the IAQ in subway stations [2-5].

IAQ can be affected by gases (including carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria), or any mass or energy stressor that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings.

Residential units can further improve indoor air quality by routine cleaning of carpets and area rugs. Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces, and computer modeling of air flow inside buildings. IAQ is part of indoor environmental quality (IEQ), which includes IAQ as well as other physical and psychological aspects of life indoors (e.g., lighting, visual quality, acoustics, and thermal comfort). Indoor air pollution in developing nations is a major health hazard. A major source of indoor air pollution in developing countries is the burning of biomass (e.g. wood, charcoal, dung, or crop residue) for heating and cooking. The resulting exposure to high levels of particulate matter resulted in between 1.5 million and 2 million deaths in 2000.

Wireless sensor networks (WSN), sometimes called wireless sensor and actuator networks (WSAN), are spatially distributed autonomous sensors used to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location [6]. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on. The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

In this paper, an indoor air quality monitoring system using a ZigBee network is studied for underground subway stations [7]. The 424MHz ZigBee module, which uses a relatively lower frequency for wireless transmission and reception, has been observed to exhibit a much higher transmission and reception rate than that of the 2.4GHz XBee-PRO in the presence of obstacles such as in subway waiting rooms, platform stairs, complicated structures, and crowded passengers. This indicates that the lower frequency radio waves have better diffraction characteristics and thus have better performance when obstructed by obstacles. Therefore, it was found that the low frequency Zigbee modules are advantageous in complex structures such as subways.

II. IAQ Monitoring Using a ZigBee Network

2.1 ZigBee network:

ZigBee is a low-cost, low-power, wireless mesh network standard targeted at the wide development of long battery life devices in wireless control and monitoring applications. Zigbee devices have low latency, which further reduces average current. ZigBee chips are typically integrated with radios and with microcontrollers that have between 60-256 KB of flash memory. ZigBee operates in the industrial, scientific and medical (ISM) radio bands: 2.4 GHz in most jurisdictions worldwide; 784 MHz in China, 868 MHz in Europe and 915 MHz in the USA and Australia. Data rates vary from 20 kbit/s (868 MHz band) to 250 kbit/s (2.4 GHz band). The ZigBee network layer natively supports both star and tree networks, and generic mesh networking. Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level. ZigBee builds on the physical layer and media access control defined in IEEE standard 802.15.4 for low-rate WPANs. The specification includes four additional key components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favor total integration. ZDOs are responsible for some tasks, including keeping track of device roles, managing requests to join a network, as well as device discovery and security. ZigBee is one of the global standards of communication protocol formulated by the significant task force under the IEEE 802.15 working group. The fourth in the series, WPAN Low Rate/ZigBee is the newest and provides specifications for devices that have low data rates, consume very low power and are thus characterized by long battery life. Other standards like Bluetooth and IrDA address high data rate applications such as voice, video and LAN communications.

ZigBee supports several network topologies; however, the most commonly used configurations are star, mesh and cluster tree topologies as shown in Fig. 1. In a star topology, the network consists of one coordinator which is responsible for initiating and managing the devices over the network. All other devices are called end devices that directly communicate with coordinator. This is used in industries where all the end point devices are needed to communicate with the central controller, and this topology is simple and easy to deploy. In mesh and tree topologies, the ZigBee network is extended with several routers where coordinator is responsible for initiating them. These structures allow any device to communicate with any other adjacent node for providing redundancy to the data. If any node fails, the information is routed automatically to other device by these topologies. As the redundancy is the main factor in industries, hence mesh topology is mostly used. In a cluster-tree network, each cluster consists of a coordinator with leaf nodes, and these coordinators are connected to parent coordinator which initiates the entire network. Due to the advantages of ZigBee technology like low cost and low power operating modes and its topologies, this short range communication technology is best suited for several applications compared to other proprietary communications, such as Bluetooth, Wi-Fi, etc.

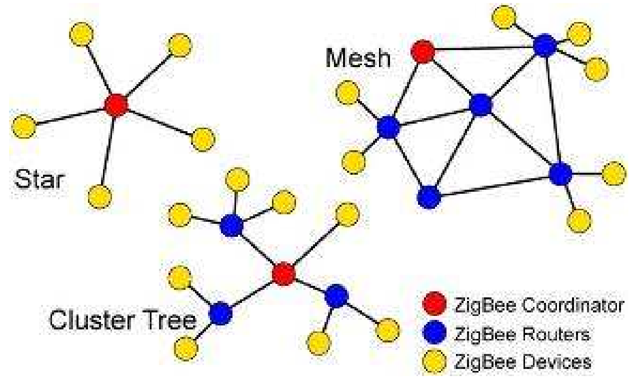

Fig.1. ZigBee topologies

2.2 Implementation of ZigBee module:

Digi XBee and Digi XBee-PRO ZigBee RF modules provide cost effective wireless connectivity to electronic devices [8]. They are interoperable with other ZigBee PRO feature set devices, including devices from other vendors. Digi ZigBee Development Kits are useful in facilitating ZigBee application development. Digi XBee and Digi XBee-PRO ZigBee modules are ideal for applications in the energy and controls markets where manufacturing efficiencies are critical. The Serial Peripheral Interface (SPI) provides a high-speed interface and optimizes integration with embedded microcontrollers, lowering development costs and reducing time to market. Products in the Digi XBee family require little to no configuration or additional development. Programmable versions of the Digi XBee and Digi XBee-PRO ZigBee module make customizing applications easy. Programming directly on the module eliminates the need for a separate processor. Because the wireless software is isolated, applications can be developed with no risk to RF performance or security. Digi's ZigBee compatible module is based on the Ember EM35x (EM357 and EM3587) system on chip (SoC) radio ICs from SiliconLabs, utilizing 32-bit ARM CortexTM M3 processor. The S2D EM3587 version has a larger memory footprint for customers who may want to upgrade to Thread, an IPv6 based networking stack. Fig. 2 shows ZCM(ZigBee coordinator modem) and ZED(ZigBee end device) developed for ZigBee network.

Fig.2 left: ZCM(ZigBee coordinator modem), right : ZED(ZigBee end device)

Wireless transceiver modules for the 424 MHz and 2.4 GHz ISM bands, as shown in Fig. 3, are used in industrial, scientific and medical devices, and their transmit power is limited to less than 10 mW. In this study, we want to identify the more suitable frequency between 2.4 GHz and 424 MHz in the underground environment for the reliable transmission of sensor data in the wireless section of the network and apply it to the underground environment detection system. To understand the characteristics of the 424 MHz and 2.4 GHz wireless transceiver modules, Copaland's UM-12K (424 MHz) and Digi's XBee-PRO (2.4 GHz) were selected and compared.

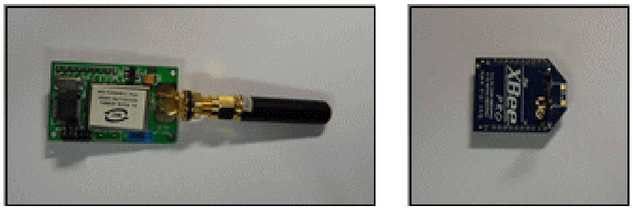

Fig.3. Wireless transmit / receive module, Copaland's UM-12K (424 MHz, left) and Digi's XBee-PRO (2.4 GHz, right)

Copaland's UM-12K is a subminiature product that enables bi-directional data communication through RS-232 protocol communication that can be widely applied to wireless meter reading, remote control, field monitoring, and data transmission.The module's wireless modem has its own CPU and protocol built-in, so that data can be transmitted bidirectionally between modems without any special operation. Data transmission between the module and the computer can be easily carried out by wired (UART, RS-232) communication. In order to confirm the frequency suitable for the wireless data transmission of the underground environment detection system, the experiment environment was structured as shown in Fig. 4 and Fig. 5 using Copaland's 424 MHz wireless transceiver module and Digi's 2.4 GHz wireless transceiver module, respectively.

Fig.4. 2.4 GHz experimental module configuration

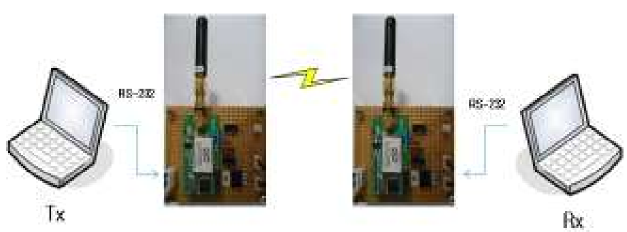

Fig.5. 424 MHz experimental module configuration

2.3 Experimental study in a subway station:

First, the performance test of wireless data transmission of 2.4 GHz and 424 MHz Zigbee modules was performed in the subway waiting room as shown in Fig. 6. Table 1 shows the results of the experiment of fixing the receiver in one waiting room and moving the transmitter around. At each location, the transmitter sent data 100 times and by measuring the number of ACK signals received from the receiver the data rate was determined. The first test result is the successful transmission rate at a point 45 meters away without obstacles, and the second is the transmission throughput at a distance of 55 meters bent in the presence of an obstacle in the middle, and lastly the transmission throughput at a point 20 meters down the stairs.

Table1. Data transfer rate of Zigbee module (test 1)

Test point	2.4GHz (10 mW)	424MHz (10 mW)
1	95%	99%
2	53%	96%
3	0%	79%

Fig.6. Waiting room in a subway station

As can be seen from Table 1, the 424 MHz ZigBee module performs better in all cases than the 2.4 GHz ZigBee module, especially in spaces with obstacles, bends, or stairways. This is judged to be because of the lower operating frequency enabling superior diffraction of the radio wave.

Secondly, the experimental results of fixing the receiver to the narrow and crowded subway platform as shown in Fig. 7 and moving the transmitter around are shown in Table 2.

Fig.7. Crowded platform in a subway station

Again, at each location, the transmitter sent the data 100 times and received the ACK signal from the receiver to determine the data transfer throughput. The first test result is the data throughput at a straight line distance of 35m with an obstacle in the middle, and the other three cases likewise the throughputs at a straight line distance of 65m, 105m, and

160m with an obstacle in the middle. As can be seen from the results in Table 2, on the narrow and crowded subway platform, the 2.4 GHz XBee-PRO is unable to produce any throughput at a distance of more than 35m in a straight line. The 424MHz ZigBee module, however, consistently outperforms the 2.4GHz XBee-PRO even though the data throughputs gradually decreased over distance.

The results of Table 1 and Table 2 show that the 424MHz ZigBee module, which uses a relatively lower frequency for radio transmission and reception, comparatively has a much better data throughput when in the presence of obstacles such as subway waiting rooms, platform stairs, complicated structures, and crowded passengers.

Table2. Data Transfer Rate of Zigbee Module (test 2)

Distance	2.4GHz (10 mW)	424MHz (10 mW)
35m	0%	91%
65m	0%	55%
105m	0%	26%
160m	0%	0%

III. Concluding Remarks

In order to implement an air quality monitoring system based on environmental sensors for the waiting room or the platform of an underground subway station, wireless sensor network systems are essential. In this paper, ZigBee modules are implemented in the sensor network system and are studied to evaluate the performance of the wireless communication for sending and receiving of measured sensor data. Experimental results show that in the presence of mixed obstacles such as subway waiting room, platform stairs, complicated structure, and crowded passengers, the 424MHz ZigBee module, which has a relatively lower frequency of radio transmission and reception, has a much higher data throughput than XBee-PRO of 2.4GHz. This indicates that the lower frequency radio waves have better diffraction characteristics and thus better performance when obstructed by obstacles. Therefore, it was found that low frequency Zigbee modules are advantageous in complex structures such as subways.

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