ZigBee: The Emerging Technology in Building Automation

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Abstract: **With the development of industrial automation technology, the limitation of traditional cable control network has become increasingly prominent. Consequently, establishing a reliable data transmission network becomes a critical demand in industry. Increasingly, companies developing monitoring and control applications in industrial and commercial building environments are looking to wireless technologies like ZigBee to save the cost of wiring and installation and also to allow more flexible deployment of systems. Zigbee was developed to satisfy the market's need for a cost-effective, standards-based wireless network that supports low data rates, low power consumption, security, and reliability. This paper illustrates that the ZigBee wireless technology can perform well in industrial environments in terms of performance and reliabilities.**

Key words: Wireless, ZigBee, IEEE 802.15.4, wireless network, Wireless measure and control system

I. INTRODUCTION

Usually, there are thousands of sensors in a factory, such as, pressure transmitters, flowmeter, temperature transmitters, level transmitter, and so on. Until now, wired networks are used to connect sensors to transfer sampled process data to control systems. Wired networks are very reliable and stable communication systems for instruments and controls. However, the cabling engineering necessary is very costly. Therefore, recently costless wireless networks are more and more strongly required by customers. Many domestic and foreign companies and research institutions start to study how to formulate industrial wireless measure and control systems. ZigBee, the short-range wireless data transmission technology, for its safe, reliable, simple and flexible, low cost, long battery life and other advantages, has shown strong potential and been the research hotspot in recent years in industrial control field [1]-[2]. Having proposed ZigBee [3] as the wireless technology to replace wire harnesses in any sensing and control application that uses wired signal and data communication. Current literature on ZigBee robustness only focuses on deterministic signals such as Wi-Fi (IEEE 802.11b, g), Bluetooth (IEEE 802.15.1), and ZigBee as the interference [4]-[6]. The ZigBee (IEEE 802.15.4) is a new technology that permits the implementation of Wireless Personal Area Networks (WPAN). It is very suitable for wireless sensor networks due to the very low power consumption. With industry standardization comes more product innovation, and the emergence of the ZigBee standard is bound to drive the whole market forward.

II. 802.15.4 STANDARD

802.15.4 is a standard for wireless communication issued by the IEEE. The IEEE is a technical professional association that has written numerous standards to promote growth and interoperability of existing and emerging technologies. The 802.15.4 standard specifies that communication can occur in the 868-868.8 MHz, the 902-928 MHz or the 2.400-2.4835 GHz Industrial Scientific and Medical (ISM) bands. While any of these bands can technically be used by 802.15.4 devices, the 2.4 GHz band is more popular as it is open in most of the countries worldwide. The 868 MHz band is specified primarily for European use, whereas the 902-928 MHz band can only be used in the United States, Canada and a few other countries and territories that accept the FCC regulations.

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│   User-defined Application Profiles  │
│      ZigBee defined Object Layer     │
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┌─────────────────────────────────────┐
│  Network and Application Support Layer │
└─────────────────────────────────────┘
┌─────────────────────────────────────┐
│    IEEE Media Access Control Layer   │
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│    IEEE Media Access Control Layer   │
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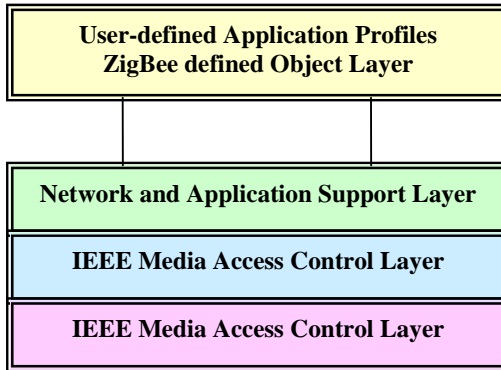
Fig. 1: IEEE 802.15.4 Stack

The 802.15.4 standard specifies that communication should occur in 5 MHz channels ranging from 2.405 to 2.480 GHz. In the 2.4 GHz band, a maximum over-the-air data rate of 250 kbps is specified, but due to the overhead of the protocol the actual theoretical maximum data rate is approximately half of that. While the standard specifies 5 MHz channels, only approximately 2 MHz of the channel is consumed with the occupied bandwidth. At 2.4 GHz, 802.15.4 specifies the use of Direct Sequence Spread Spectrum and uses an Offset Quadrature Phase Shift Keying (O-QPSK) with half-sine pulse shaping to modulate the RF carrier.

III. ZIGBEE PROTOCOL

The complete ZigBee protocol specifications were ratified in December 2004 [3], involving the collaboration of about 70 firms (over 200 firms are currently participating in the consortium). The aim was to develop a low-cost, low consumption wireless communication system with an average data transfer rate, for use in consumer electronics, computers and peripherals, control of residential lighting systems, industrial control, automatic construction systems and monitoring of medical variables[7]-[9], etc. In comparison with other wireless communication systems, the

ZigBee stack (Fig. 2) can be considered to be small: 4 Kb for the simplest nodes and 32 KB for the complete stack. ZigBee offers a layered architecture based on the MAC and physical layers of the IEEE 802.15.4 standard. This design offers low power consumption and guarantees a longer battery life, which is one of the most important issues of wireless networks. Since ZigBee is based on IEEE 802.15.4 it inherits a low data rate, and a reception distance of about 100 meters (depending on environmental conditions). The following table 1 offers a comparison of features with several other popular wireless technologies and their different applications.

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┌──────────────────────────┐  ⋮
│       Applications        │  ▲
└──────────────────────────┘  │
┌──────────────────────────┐  │  ZigBee/User
│    Applications Profiles  │  │
└──────────────────────────┘  │
┌──────────────────────────┐  ▼
│   Applications Framework  │ ⋯⋯⋯
└──────────────────────────┘       ▲
┌──────────────────────────┐       │
│  Network and Security Layer │     │
└──────────────────────────┘       │  ZigBee
┌──────────────────────────┐       │
│        MAC Layer          │     ⋯⋯⋯
└──────────────────────────┘  ▲  │
┌──────────────────────────┐  │ IEEE 802.15.4
│      Physical Layer       │  ▼
└──────────────────────────┘  ⋯⋯⋯
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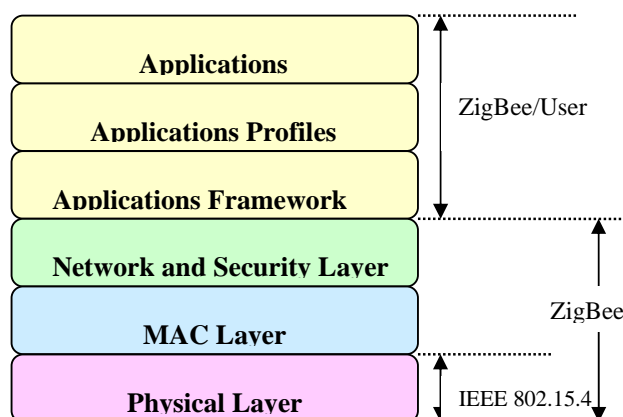
Fig. 2: ZigBee Protocol Stack

For the upper layers one of the most important characteristics of ZigBee is the possibility of using one of two types of routings: mesh and tree. This gives the application designer much more freedom to get the maximum gain out of each option depending on the very own needs of the solution they develop. The protocol also offers a framework application to make easier and faster the development of simple standard applications. Also, in order

to promote the reuse of already existing functionalities, libraries and profiles have been created to facilitate the construction of the most frequently needed devices within the application environments that ZigBee has been created for. This is why ZigBee can not only be considered as a simple set of commands for the communication between sensor nodes, but as a whole framework that allows the creation of standard devices, assuring the interoperability between different manufacturers.

ZigBee wireless networks meet IEEE's 802.15.4 standard in the physical layer and medium access layer. The network layer, the security service and the application interface have all been defined by the ZigBee alliance. The specific application is run in the upper stack level. The IEEE 802.15.4 protocol makes it possible to obtain speeds up to 20 kb/s (@ 868 MHz), 40 kb/s (@ 915 MHz) and 250 kb/s(s 2.4 GHz) in distances between 10 and 100 meters using a half duplex radio transceiver and configured as star, hybrid networks or peer-to-peer typologies. Its power consumption is usually lower than WiFi or Bluetooth networks. Another of the advantages of ZigBee devices is the speed with which new nodes can be added to the network: 30 ms; while a sleeping node wakes up in 15 ms, whereupon communication can be started with other nodes; this aspect might be vital in many industrial applications[11]-[13].

	ZigBee and 802.15.4	GSM/GPRS CDMA	802.11	Bluetooth
Focus Application	Monitoring and Control	Wide Area Voice and Data	High-Speed Internet	Device Connectivity
Battery Life	Years	1 Week	1 Week	1 Week
Bandwidth	250 Kbps	Up to 2 Mbps	Up to 54 Mbps	720 Kbps
Typical Range	100+ Meters	Several Kilometers	50-100 Meters	10-100 Meters
Advantages	Low Power, Cost	Existing Infrastructure	Speed, Ubiquity	Convenience

Table 1: Comparisons of ZigBee with other wireless technologies

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.The ZigBee protocol is designed so that if a number of different radios were deployed as in the figure above, the radios would automatically form a network without user intervention. The ZigBee protocol within the radios will take care of retries, acknowledgements and data message routing. ZigBee also has the ability to self-heal the network. If any of the radio was removed for some reason, a new path would be used to route messages from source to destination.

Devices in the ZigBee specification can either be used as End Devices, Routers or Coordinators. Routers can also be used as End Devices. Since the ZigBee protocol uses the 802.15.4 standard to define the PHY and MAC layers, the frequency, signal bandwidth and modulation techniques are identical. Because ZigBee was designed for low power applications, it fits well into embedded systems and those markets where reliability and versatility are important but a high bandwidth is not. One of its advantages is that any node can send a message to another node, using as many intermediate elements as may be necessary as relays.

A ZigBee network can have two types of devices [3]. **Full Function Device:** (FFD) has full functionality and can act as network coordinator, router or even as a **reduced function device** (RFD). The coordinator (unique in the network) has the capacity of structuring the network, establishing an addressing scheme, keeping the address tables and is the only network element with the capacity for communicating with other networks; it also carries out the router functions. Routers also have to be able to forward messages, discover neighboring devices and build up a map of the routes to other nodes; normally they are active, communicating with network members. Reduced Function Devices communicates only with its network coordinator or near router, so it cannot carry out network coordinator functions. It is assumed to be one of the network's ends and it acts or reads information from the physical medium (end point device), its implementation being simpler. This device normally runs in sleep mode, to save energy, and wakes up whenever it has to receive or send a message.

IV. ZIGBEE FOR POWER SYSTEM

ZigBee technology is completely suitable for the application in power monitoring system [7], and it can provide reliable protection for the operation of electric power systems. Following are the points justifying this statement.

- Large capacity. Each ZigBee network can support up to 65,000 nodes. It is suitable for the complex structure of power system.

- The maximum transfer rate can be up to 250 kbps which is in full compliance with data rate needed by the power monitoring system.
- Strong anti-interference. For the interferences from environments such as cars, mobile phones, generators, power distribution room, transformers and so on, ZigBee technology can prevent well.
- Low-cost. The installation cost is low, and maintenance is simple, further more, there is no need to hire the public network, so there is no need to pay huge amounts of operating costs [4].
- Low power-cost. In low power standby mode, two 5th ordinary dry-cell batteries can be used for 6 months to 2 years. This is the unique advantage of ZigBee to ensure that the monitoring system continue working in the event of the power failure.
- Short time delay. The delay usually lasts for 15 ~ 20 ms, so it is very suitable for industrial real-time data transmission system.
- Strong safety. The encryption algorithm uses AES-128 which provides the functions of integrity data checking and authentication.

V. ZIGBEE IN INDUSTRIAL CONTROL

The main concern from manufacturers of industrial control and building automation systems considering any wireless technology are around robustness and security **ZigBee** addresses both concerns[14][15]. First, ZigBee networks are self-healing, rebuilding themselves when nodes drop out of the network and repairing routes when the preferred route for wireless traffic is blocked – something that is very likely to 'happen in an industrial or commercial building environment over time. Robustness is provided by a powered mesh network providing multiple potential paths for data packets en route to their destination.

Secondly, the ZigBee standard includes security on a number of levels, **from** basic authentication to 128 bit AES encryption, with keys delivered to **joining** nodes by a trust centre. **Security** is also enhanced by strict mechanisms for forming, joining and allowing new nodes onto the network when and for how long they will allow nodes to join the ZigBee Coordinator and ZigBee Routers can decide network.

VI. WIRELESS SENSOR NETWORKS BASED ON ZIGBEE TECHNOLOGY

The ZigBee technology allows the operation in so called mesh networks that are low cost, self organizing networks of ZigBee devices. The components of the mesh networks can operate over extended periods of time, even years, without changing the original battery. The ZigBee devices operate in unlicensed radio frequency bands (ISM). These unlicensed bands are not the same in all regions of the world, those the ZigBee devices can operate in three frequency bands centered on 868, 915 and 2400MHz.

Frequency Band[MHz]	Data rate [kb/s]	Channel numbers	Geographical area
868,3	20	1	Europe
902-928	40	1-10	America, Australia
2405-2480	250	11-26	Worldwide

Table 2: Frequencies and data rates in ZigBee.

The most advantageous frequency band is at 2400MHz because of higher data rate (250kb/s) and the worldwide availability. In the 2402–2480 MHz frequency band is used offset quadrature phase-shift keying (O-QPSK) modulation technique. In the 868 and 902-928 frequency bands are used DSSS (Direct sequence spread spectrum) and BPSK (Binary phase shift keying).The use of O-QPSK and BPSK minimize power consumption and reduce complexity.

The ZigBee Alliance designed ZigBee with very different application environments in mind: home automation, commercial buildings, industrial automation, and medical instrumentation. Given this diversity, the first problem the Alliance has been trying to solve is the interoperability between different vendors, which is why their tests suites have had more emphasis on compatibility than on the performance of the protocol.

A. Characteristics of ZigBee

ZigBee is poised to become the global control/sensor network standard. It has been designed to provide the following features:

- Low cost (device, installation, maintenance). Low cost to the users means low device cost, low installation cost and low maintenance. ZigBee devices allow batteries to last up to years using primary cells (low cost) without any chargers (low cost and easy installation). ZigBee's simplicity allows for inherent configuration and redundancy of network devices provides low maintenance.
- Low power consumption, with battery life ranging from months to years.
- High density of nodes per network: ZigBee's use of the IEEE 802.15.4 PHY and MAC allows networks to handle any number of devices. This attribute is critical for massive sensor arrays and control networks.
- Maximum data rates allowed for each of the frequency bands are fixed as 250 kbps @2.4 GHz, 40 kbps @ 915 MHz, and 20 kbps @868 MHz.
- Different topologies like: star, peer-to-peer, mesh
- High throughput and low latency for low duty-cycle applications (<0.1%).
- Channel access using Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA).
- Addressing space of up to 64 bit IEEE address devices, 65,535 networks.
- 70-100m range.
- Fully reliable "hand-shaked" data transfer protocol.

B. Applications of ZigBee

ZigBee networks consist of multiple traffic types with their own unique characteristics, including periodic data, intermittent data, and repetitive low latency data. The characteristics of each are as follows:
• Periodic data – usually defined by the application such as a wireless sensor or meter. Data typically is handled using a beaconing system whereby the sensor wakes up at a set time and checks for the beacon, exchanges data, and goes to sleep.
• Intermittent data – either application or external stimulus defined such as a wireless light switch. Data can be handled in a beaconless system or disconnected. In disconnected operation, the device will only attach to the network when communications is required, saving significant energy.
• Repetitive low latency data – uses time slot allocations such as a security system. These applications may use the guaranteed time slot (GTS) capability. GTS is a method of QoS that allows
 each device a specific duration of time as defined by the PAN coordinator in the Superframe to do whatever it requires without contention or latency.
Reduced Function Device (RFD) meter wakes up and listens for the beacon from the PAN coordinator, if received, the RFD requests to join the network. The PAN coordinator accepts the request. Once connected, the device passes the meter information and goes to sleep. This capability provides for very low duty cycles and enables multi-year battery life. Intermittent traffic types, such as wireless light switches, connect to the network when needed to communicate (i.e. turn on a light).
For repetitive low latency applications a guaranteed time slot option provides for Quality of Service with a contention free, dedicated time slot in each super frame that reduces contention and latency. Applications requiring timeliness and critical data passage may include medical alerts and security systems. In all applications, the smaller packet sizes of ZigBee devices results in higher effective throughput values compared to other standards. ZigBee networks are primarily intended for low duty cycle sensor networks (<1%). A new network node may be recognized and associated in about 30 ms. Waking up a sleeping node takes about 15 ms, as does accessing a channel and transmitting data.
ZigBee applications benefit from the ability to quickly attach information, detach, and go to deep sleep, which results in low power consumption and extended battery life.

VII. CONCLUSION

Wireless communication technologies can often be useful within industrial applications. An advantage of using ZigBee radio technology in the implementation of measuring and monitoring systems is represented by flexibility in topology of the sensor network. This offers the possibility to reorganize very rapidly the systems. Also the components of the ZigBee mesh networks can operate over extended periods of time, even years, without changing the original battery.
ZigBee is necessary if you need to use repeating or mesh networking functionality in your system. ZigBee technology together with other wireless technologies will profoundly and completely change the aspect of the industrial automation system.

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