Industrial Automation and Sensing using ZigBee

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ABSTRACT
This paper basically compares various wireless networking technologies which can be used for industrial automation and sensing. Among all these technologies, special emphasis is given on Zigbee. Zigbee is a technology known for its low power consumption, low data rates, and self-healing reliable networks, which makes it very efficient for industrial applications. The layer by layer protocol stack architecture of Zigbee illustrates these advantageous features. Zigbee is used for automation and networking purposes in manufacturing and pharmaceutical plants, for monitoring purposes in chemical plants. In this paper, such features and applications of Zigbee are explained with concentration on the networking aspect.

Keywords
Automation, Sensing, Zigbee, Networking, Protocol Stack, Applications, Industry

1. INTRODUCTION
Automation is playing a very important part nowadays for many manufacturing and packaging industries. It also plays an integral part in many processes of pharmaceutical industries. Also, in big chemical plants, many different processes are taking place in sections which are situated at very large distances from each other. So, to keep a record of various parameters of the chemicals, sensors which can measure temperature, pressure, pH value, etc. are added. But, due to the large distance and the considerable amount of processes being undertaken, maintaining a record of each and every process individually is impractical. So, a network is created which will connect all the sensors and the values of all these sensors will then be transmitted to a common server. A database will be maintained of all these values in that server. So, in case of any problems in any part of the plant, there can be easy detection and correction.

To create such networks for automation and sensing, both wired mode as well as wireless mode can be used. But, there are numerous problems regarding the use of wired mode. The first disadvantage in using wired communication is the amount of cabling required. Cost of installing and maintaining cables used for communication is very high. Also, these cables have to be properly terminated which itself adds up to the already high cost of installation. Once these cables are laid, making any changes in the future is very difficult as the whole layout has to be planned and executed again. But, in wireless communication, most of these problems do not occur. The cost of installation is not as high as that of wired communication. Maintaining a wireless network is simpler and also any changes in the network can be easily made and re-planning of the whole layout is not always necessary.

There are numerous different standards available in wireless mode of communication like Bluetooth, Zigbee, Wi-Fi, etc. Out of these standards, Zigbee has many advantages over others such as low cost, low power consumption, etc. It can connect large number of devices by creating a mesh network. Bluetooth and Wi-Fi have lower area coverage than Zigbee and also the power consumption of the modules is higher as compared to Zigbee. So, Bluetooth is basically used for very close range communication and Wi-Fi is used for creating WLANs (Wireless Local Area Networks) and connecting those networks to the internet. If high data rates are required in a network then Wi-Fi can be used. But, usually in industries power consumption is a bigger issue than data rates and so Zigbee has advantage over Bluetooth and Wi-Fi. Following table shows the difference between some of the standards used for wireless networking.

Table i. Comparison of various wireless communication standards

Parameters	Standards		
	Zigbee	*Bluetooth*	*Wi-Fi*
Standard	802.15.4	802.15.1	802.11
Battery Life	Years	Days	Hours
Application	Monitoring and Control	Cable Replacement	Web, Email, Video streaming
System Resources	4kB – 32kB	250kB+	1MB+
Network Size	Around 65000	7	32
Bandwidth (kbps)	20 – 250	720	11000+
Range (meters)	1 – 100+ can go up to 1000	1 – 10+	1 – 30+
Topology	Mesh, Star, Tree	Star	Star
Optimized for	Reliability, Scalability, Low Cost, Low power	Low cost, Convenience	Speed
Latency	30 ms – 1 sec	10 sec	3 sec
Security	128 bit AES and application layer	64 bit, 128 bit	CCMP/ TKIP 128bit/ 64bit

2. MORE ABOUT ZIGBEE

IEEE 802.15 was created as a standard which can be used for WPANs (Wireless Personal Area Networks). There were seven different configurations in IEEE 802.15 in which one of them was IEEE 802.15.4 which was first launched in May 2003. The standard was basically introduced for defining the physical and MAC (Medium Access Control) layers of WPAN [1]. The 802.15.4 based standard provides data transmission on three frequencies. At 868 MHz it provides 20 kbps, at 915 MHz it provides 40 kbps and at 2.4 GHz it provides about 250 kbps of data transmission.

Zigbee basically uses the IEEE 802.15.4 physical radio standard and can provide data rates up to 250 kbps at 2.4 GHz. Also, Zigbee has an advantage of easy expansion of networks as every single node can support more than 64,000 devices using the Zigbee addressing scheme. So, a large network can be created using Zigbee at low cost and low power usage as Zigbee standard allows many devices to sleep when not in use. A single Zigbee based networking device range can go up to thousands of meters and the radio power outage ranges from 1mW to 100mW. This low power consumption of the networking devices reduces the overall power consumption considerably.

The 802.15.4 standard is basically used for low power consumption, relaxed data rates, limited area coverage and low manufacturing and maintenance costs. Such factors are very important in manufacturing plants while creating wireless networks. Also, in a Zigbee based network, there are three types of networking devices [3] [4]:

2.1 The Coordinator

Its function is to initiate network formation. Only one coordinator is required per network. The functions of the coordinator also include configuration of channels PAN ID and Stack Profile. After formation of the network, the coordinator works as a central node of the network.

2.2 The Router

A router is not always compulsory in a network. Its main function is to participate in a mesh routing or multi-hop routing of messages in a network. Routers maintain a routing table and also one of the functions of a router is allocation of addresses to end devices. The routers are basically used for

2.3 The End Device

This device is also an optional device in a network. The end devices in a Zigbee based network can be configured for power saving by putting the devices in sleep mode when not in use.

To save power, the Zigbee devices work in two different modes viz. the beacon and the non-beacon mode. In the beacon mode, the routers are not always active. They send periodic beacon signals which confirm their existence in the network and when they are not transmitting or are not sending beacon signals, the devices can sleep and save power. In the non-beacon mode, the routers and end devices are continuously active.

The Zigbee protocol stack or the layer-by-layer architecture of the Zigbee standard shoes us that it basically works above the Physical and MAC (Medium Access Control) layers of the 802.15.4 IEEE standard. It is basically defined in the network and the security layer. Zigbee can be used in Star, Mesh or Tree network topologies and by default Zigbee supports the mesh networking topology. Also, Zigbee network provides 32/ 64/ 128 bit AES (Advanced Encryption Standard) based encryption of the transmitted data.

**Fig. 1: Zigbee Protocol Stack [5]**

Zigbee is used in various applications such as:

1. Home Automation
2. Industrial Automation
3. Building Automation
4. Wireless Sensor Networks
5. Health Care
6. Smart Energy
7. Telecom Services
8. Remote Control

3. NETWORKING USING ZIGBEE

A Zigbee based network can be created in mesh and star topologies [5]. Zigbee devices can also be used as a tree based network topology. The connection of various Zigbee based devices such as the coordinator, the router and the end devices according to various topologies are as shown in the figures below:

All these networks have to be connected to a gateway device if these networks are required to be connected to the internet. Then the devices connected to these networks can be easily monitored and controlled from any location where internet is available. Then the devices connected to the networks can be controlled via any smartphones. A Zigbee based stand-alone system can also be created.
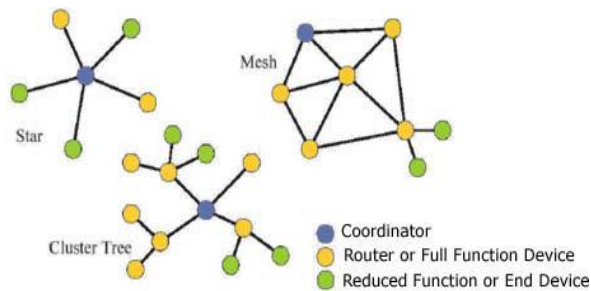
Fig. 2: Different types of network topologies in which Zigbee based devices can be connected.

Communication and networking using Zigbee happens in the following manner. At first the Coordinator, which is responsible for starting the network, searches for a free radio channel or a channel with least activity. Then the coordinator assigns a PAN ID (Personal Area Network Identifier) to the network. Here, the PAN ID can be determined or set before the start of the network or the PAN ID can also be determined by detecting other networks which are already using a PAN ID and setting an ID which is not in use by those networks. After configuring itself, the coordinator then starts itself in coordinator mode.

After configuration of the coordinator, other Zigbee modules can be configured as routers and end devices. The same PAN ID which is configured by the coordinator has to be used by those modules. The coordinator responds to the queries of all these modules who wish to join the network.

4. USE OF ZIGBEE IN INDUSTRIES

The main requirement of the industries is low use of power. So, Zigbee is one of the technologies which are being used in multitude of industrial applications. Manufacturing and chemical plants, pharmaceutical industries, etc. want to save on manufacturing costs. So, to reduce costs in manufacturing of products, the industries will always try to save as much as possible in power usage. Zigbee has low power consuming modules and also provides adequate range for creating a wireless network inside a plant. Also, Zigbee has an inherent advantage of easy expansion of networks and using gateway, the Zigbee based networks can be connected to the internet and can help in remote monitoring of all the processes running in the industrial plants [6].

4.1 Manufacturing Plants

Manufacturing industries [7] have many different types of robots each with their own complex physical and logical structure. Every robot is connected with numerous sensors which help in automating the whole process. So, once the robot is programmed for a specific task, the sensors then continuously monitor the task being undertaken by the robot and help the robot to perform that task optimally. These sensor values have to be monitored continuously by a system. The system consists of controllers and processors which process the data provided by the sensors and then send control signals to the robots. Now, big manufacturing plants can have hundreds of such robots and taking values of sensors of each robot individually and processing those values is impractical. So, these sensors can all be connected using Zigbee modules and a network can be formed of such sensors. These modules can be then connected in a star or tree topology where each module is connected to the central Coordinator module. The coordinator is connected to a main system where the values of all the sensors are input and processing is done. Then, according to the task of the robot, different control signals can be sent to every robot.

In many plants nowadays mobile robots are used at a large scale. These robots are used to reduce human intervention in the transportation part of the manufacturing processes. These robots are used as they can be sent in places which are hazardous to humans. Controlling of these robots can also be done using Zigbee. The modules which are connected to these robots can also be joined to the same network in which all the assembly line based robots are connected. But, then the whole network, or the modules connected to the mobile robots have to be connected to the main network using mesh topology. That is because the modules connected to the mobile robots will be constantly changing positions inside the network. So, at different instances of time, the modules need to be connected to different routers for continuous transmission of data.

4.2 Chemical Plants

In chemical plants, usually various types of sensors are to be found. Big chemical plants contain hundreds of chemical processing units and each unit can contain various sensors which detect the pressure, temperature, pH value, sensors for detecting different gases, emissions, etc. So, in such way, there can be thousands of sensor groups which are assigned specific measuring and sensing tasks. All these different sensor configurations can be interconnected using Zigbee [8]. This will make the process of monitoring all the units very easy. An alarm system can be created in case any problems occur in the plant. Also, when the sensor units connected to Zigbee modules are not in use, the module can be kept in sleep mode and the efficiency of the whole network can be increased.

Even in chemical plants, the Zigbee modules can be attached to the transportation vehicles to continuously monitor the chemicals stored. Using the modules, the chemicals can be monitored whenever they are being transported from one area of the plant to other. Zigbee can also be used for entry and exit detection of each transport vehicle.

4.3 Pharmaceutical Industries

These industries consist of a combination of automation as well as sensing. So, the amount and the type of networking required for interconnecting the sensors of all the units if pharmaceutical industries is complicated. These industries have chemical plants as well as manufacturing plants. The chemical plants process different types of medicines and the manufacturing and packaging plants pack these medicines into capsules and bottles.

So, the amount and the type of sensors which are required for automating the whole chemical processing, medicine manufacturing and packaging of these medicines into bottles will be very large. So, all these processes are split into different industries or different plants. But, there has to be a proper link between all them as an improper link will reduce the efficiency of production. So, for that, a wireless sensor network is a definite requirement. Zigbee can be used to make such large networks as it has an advantage of easy network expansion. A Gateway can be used to connect all the networks to the internet. Then, using the internet, networks which are situated at very large distances can also be connected to each other.

The uniqueness of networking in pharmaceutical plants is that the data related to sensors which are used for automation and monitoring have to be segregated by the central monitoring system. Segregation of data is important as different control signals have to be sent to every robot performing a specific task. At the same time, the system has to monitor the sensor values for any unusual activity and take immediate precautionary measures accordingly.

5. FUTURE SCOPE OF ZIGBEE

Zigbee is fast becoming one of the most used wireless networking standard. That is because of its ease of expansion and low power consumption. Zigbee is also used for its interoperability. Nowadays, cellular radiation is one of the problems affecting the lives of people. So, the device used for checking radiation of the base station towers is to be taken near the tower for radiation measurement. Instead of that, if the radiation measuring device is installed with the towers and a Zigbee module is connected to the measuring device, then a network can be created which will send continuous updates to the main system using which radiation can be controlled.

Also, using the gateway device, the Zigbee based devices can be connected to the internet. So, a local or a personal network of an industry can be easily connected to the internet and the data of various such industrial plants can be transferred to a single location for monitoring. The only parameter which has to be considered very carefully is security.

6. CONCLUSION

Thus, Zigbee is a standard which can be used for industrial automation and sensing due to advantages such as low power consumption, good coverage area, reliable network structure and easy expansion of network. Although it has lower data rates as compared to Bluetooth and Wi-Fi, low power consumption and high capacity for connection of devices, which Zigbee provides, are of more importance in industrial applications.

Also, Zigbee is a standard which has many future prospects in communication. It is being widely used in wireless home automation, in remote controls, and in any kind of networking device. Zigbee devices can also be connected to the internet which can be used for expansion of networks.

Thus, if low power and long life of communicating devices is required, then Zigbee is the perfect communication standard which can be used by the industries. Also, the demand for Zigbee is increasing for such automation applications. One more important parameter of Zigbee is its self-healing characteristic which makes its networks most reliable in extremely noisy environments.

7. ACKNOWLEDGMENT

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