ZigBee

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Introduction

ZigBee, known as low speed wireless personal local area network (LR-WPAN: Low Rate Wireless Personal Area Network) communication in wireless communication technologies, enables many different devices to establish a connection so that they can work simultaneously. Zigbee is an IEEE 802.15.4-based feature for a suite of high-level communication protocols used to build personal area networks with small, low-power digital radios such as home automation, medical device data acquisition and other low power consumption. It is designed for small-scale projects with low bandwidth needs and wireless connectivity.

Working on ZigBee-style networks has been started since 1998 due to the inadequacy of wireless communication technologies such as Wi-Fi and Bluetooth in some applications. In these studies, the main target was to produce products that are low cost, high reliability, energy efficient and suitable for establishing networks for imaging and management. The installation of ZigBee 1.0 was realized by IEEE in May 2003 with the completion of the 802.15.4 standard. On December 14, 2004, ZigBee features were approved. ZigBee was first released in June 2005. ZigBee 2007 was released on September 30, 2007 with new technical features. Finally, home automation, the first ZigBee application profile, was put into use on November 2, 2007 (Yuksel, 2010).

ZigBee Alliance; It is a worldwide unit responsible for the standards of ZigBee technology, founded by many companies to produce reliable, low cost and low power consumption products. This community; works on the standards of products for display and control purposes.

ZigBee Protocol Stack

The ZigBee protocol stack consists of a series of blocks called layers, based on the International Organization for Standardization (ISO) open system interconnection (OSI) reference model. These layers are defined by IEEE 802.15.4 and the Zigbee Alliance. The OSI model defines how applications running on devices with network connectivity

will communicate with each other. Layers transmit data and command directly the upper and lower layers. It consists of seven layers in the OSI model. Zigbee model uses layers which are important for low power and low data rate wireless network communication. The Zigbee model consists of four layers: physical layer, media access layer, network layer and application layer. Physical layer and Media Access Control sublayer are defined by IEEE 802.15.4, while Network layer and Application layer are defined by Zigbee Alliance (Ali, 2020).

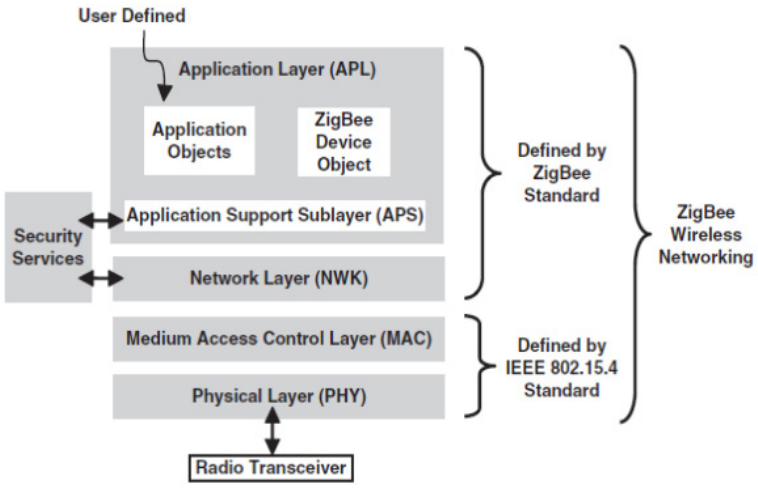

Figure 1. ZigBee and IEEE 802.15.4 Protocol Stack

Physical Layer

The physical layer provides two services, PHY data services and PHY management service. The PHY data service enables the PHY Protocol Data Unit to be transmitted and received over the physical radio channel. The PHY management service Physical Layer Management Asset service interfaces to the access point. There are three available frequency bands defined by IEEE 802.15.4, 868 MHz in Europe, 915 MHz in the USA and Australia, and 2.4 GHz worldwide. The 2.4 GHz band provides a data rate of 250 kbps, 915 MHz provides 40 kbps, and 868 MHz provides a 20 kbps data rate.

MAC Layer

The Mac layer is the layer where channel access, frame update, pointer management and association with the PAN coordinator functions. It provides a secure connection between two nodes. It performs processes such as encryption of data and access of data. The other task is to watch when the channel is empty for transmission (Sagır, 2016).

Network Layer

The network layer handles the setup of the network. Allows a new device to join or leave the network. Configures stack settings. It performs the process of assigning the addresses of the devices newly joined to the network. It determines the direction discovery of

packets sent on the network. Cancels unreliable packages (Bascifci, 2011).

Application Layer

The application layer handles the management of the network. It provides a secure communication between network devices. It regulates the operations that the devices will perform with each other. It enables the use of layer services in line with the requirements of two or more devices and directs them accordingly (Bascifci, 2011).

ZigBee Network Architecture

ZigBee technology basically enables devices to communicate with each other using RF technique. ZigBee network constitutes the main component of WPAN. It consists of various devices classified as physical and logical. Devices in the physical category can be classified as a Fully Functional Device (FFD) and Reduced Function Device (RFD). FFD and RFD devices act as a sensor node and a control node. However, only the routing functions of a ZigBee network are performed by FFD devices. Logical devices are divided into three as ZigBee Coordinator (ZC), ZigBee Router (ZR) and ZigBee End Device (ZED). Among these logical devices, ZC is the most capable device to build the network. Each ZigBee network must have a ZC. ZR functions as intermediary devices that allow data to pass to other devices. ZED, on the other hand, has limited functionality for communicating with main nodes. ZigBee network architecture is shown in Figure 2 (Ali, 2020).

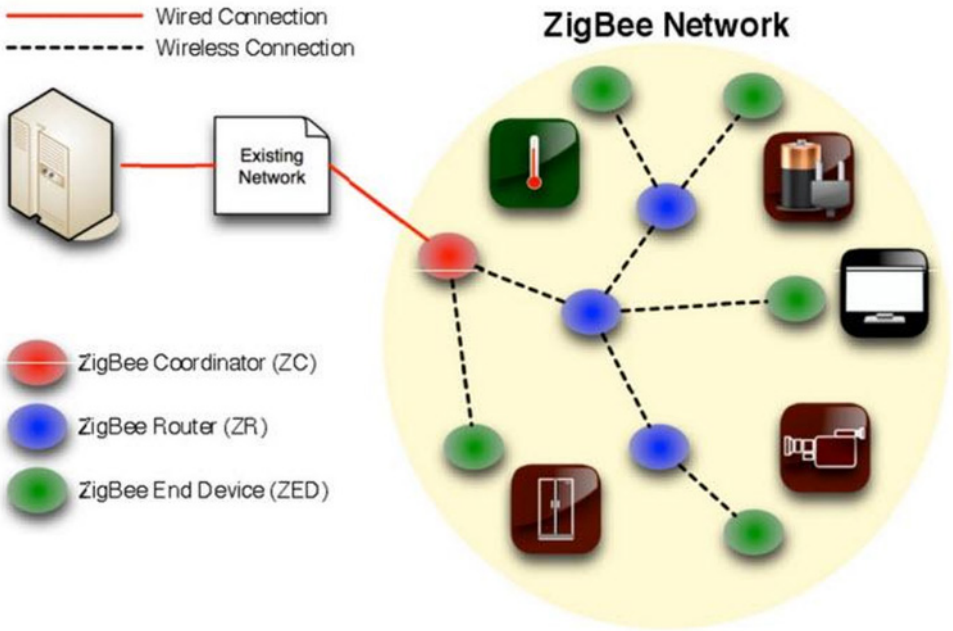

Figure 2. ZigBee Network Diagram

ZigBee Network Topology

ZigBee supports three different types of wireless network topologies: star, tree and mesh topologies.

Star Topology

Star topology is the simplest and most limited topology found in ZigBee. All devices in the star network topology are connected to a single coordinator node and all communication is carried out through this coordinator. The biggest disadvantage of this topology is that when the network coordinator becomes inoperable, the network also becomes inoperable. Because there is no alternative way from source to destination. Figure 3 shows the structure of the star topology.

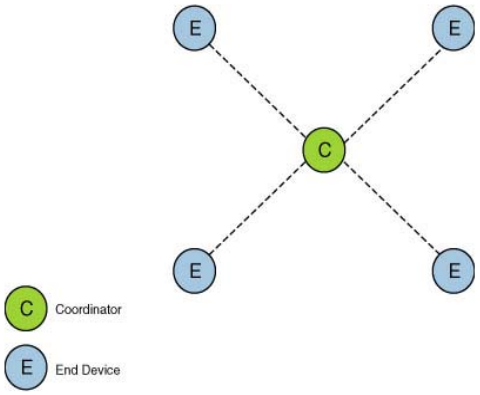

Figure 3. Star Topology Structure

Mesh Topology

It is one of the most flexible topologies offered by ZigBee. Unlike star topology, there can be many different paths on the network, and each device on the network can communicate with other devices on the same network. Since it has a route finding feature, if any device fails on the network, it finds the best route to a specific node. In mesh topology, it is easy to add and remove devices from the network. Figure 4 shows the structure of the mesh topology.

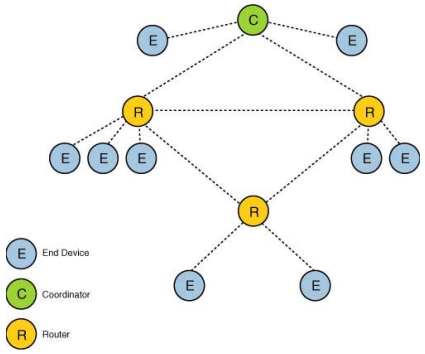

Figure 4. Mesh Topology Structure

Tree Topology

In tree topology, the coordinator and the router are called upper nodes, and the end devices are called sub nodes. Direct communication can only occur between a parent node and a child node. The tree topology is shown in Figure 5.

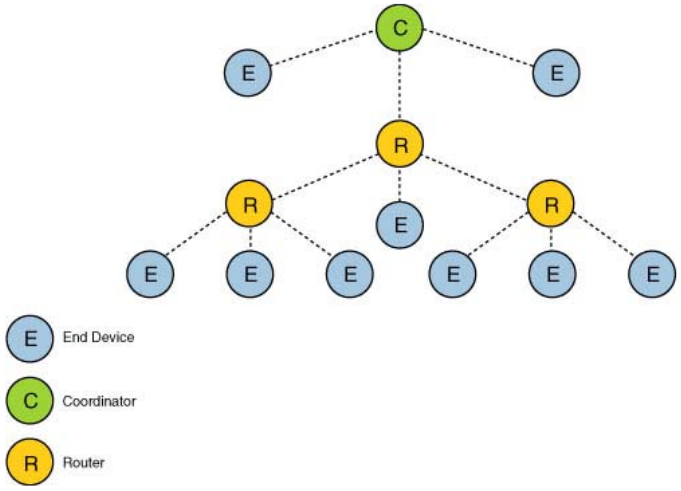

Figure 5. Tree Topology Structure

ZigBee Power Consumption

As seen in the graph below, ZigBee devices save energy by going into sleep mode depending on the data transmission times. In this way, the usage time of the battery is quite prolonged with the sleep cycles that last for hours (Gislason, 2008).

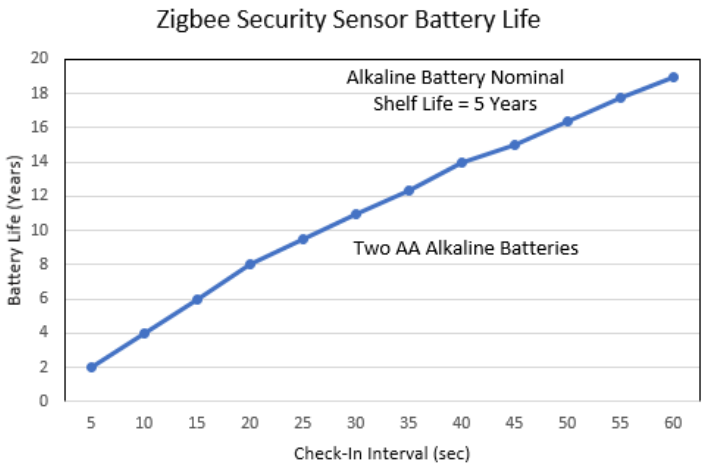

Figure 6. ZigBee Sensor Battery Life

Table 1. Comparative Power Consumption Test Results Of Bluetooth, Zigbee And Wifi

	Bluetooth	ZigBee	Wi-Fi
IEEE Spec	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.11b
Type of Module	HC-05	XBee Series 1	Arduino Yun*
Sleeping Mode	9 µA	12 µA	30 µA
Awake Mode	35 µA	50 µA	245 µA
Transmitting Mode	39 µA	52 µA	251 µA
Receiving Mode	37 µA	54 µA	248 µA
Power Supply	3.3 V	3.3 V	5 3.3 V
*The ESP8266 module which is also powered by 3.3 V could be used as the Wi-Fi modüle. Arduino Yun was used so as not to duplicate Wi-Fi modüle.			

The table above shows the power consumption of low energy wireless standards. (Kazeem et al., 2017)

Security

ZigBee uses AES-128 bit, a powerful encryption technique. This encryption technique can prevent attacks on the network. ZigBee systems provide evidence and check whether the message has arrived at the correct location. In addition, with the high security techniques used in the systems, the attacker is prevented from acting like another device. This evidence used can be used at the device level as well as at the network level. Network level authentication used in ZigBee systems is provided using a common network key. At the device level, authentication is achieved using only one connection key. Encryption in ZigBee systems can also be used as network level and device level evidence. The public network key is used for network level encryption. In this way, the attacker is prevented from infiltrating the system by using very little memory. The shared key is used for device level encryption (Yuksel, 2010).

Scope of Application

Distance and Accuracy

The communication distance between Zigbee devices can be up to 100 meters and this distance can be reduced according to the difference of the environment in which these devices are located. In addition, the size of the data packet to be sent affects the success of the transmission. 200 different data strings with a length of 64 bytes were sent by the transmitter and the successful transmission percentage values in Table 2 were obtained by comparing with the data received by the receiver (Somay, 2009).

Table 2. Zigbee's Transmission Distance (according to the medium)

	Distance	Interior	Outdoor
Unimpeded	2 meter	%100	%100
	4 meter	%100	%100
	10 meter	%100	%95,5
Unimpeded, Mobile	2 meter	%100	%100
	4 meter	%99	%100
	10 meter	%96	%95
Glass Barrier	2 meter	%100	----------
	4 meter	%100	----------
	10 meter	%99	----------
Glass + Plastic Barrier	2 meter	%90	----------
	4 meter	%86,2	----------
	10 meter	----------	----------

Usage Areas of ZigBee

The use of ZigBee networks is widespread. Usage areas and sample network models are discussed in many different categories in the literature.

- Commercial building automation (such as stock tracking, ambient temperature tracking, energy level control)
- Home automation (such as fire, indoor temperature and humidity control), home entertainment (such as smart lighting, film and music, sound and video systems adjustment)
- Livestock sector (tracking the productivity of dairy cows, detecting missing animals in the pen)
- Agriculture and agricultural crop protection (such as plant height, leaf size measurements)
- Mobile applications (like m-payment, m-monitoring, m-security and access control, m-healthcare and tele-assist)
- Other applications are automatic measurement reading, wireless telemetry, chemistry, paint, pharmaceutical industry (such as monitoring chemical processes, product quality control), water treatment, waste cleaning (in gigantic water treatment plants sensors are added to the section where each pump is located and real-time measurement data is sent to the control room)

In addition to all these, it is seen that ZigBee networks are preferred in a wide range of

areas such as military applications, ecological monitoring studies and medical monitoring applications, which are one of the exit applications of this technology.

Comparison of ZigBee and Other Wireless Communication Technologies

As seen in Table 1 and Figure 1, ZigBee has an advantage over other wireless communication technologies in terms of long battery life and network expansion capacity, while it falls behind in terms of data transmission speed in Table 3. These features make ZigBee technology a suitable candidate for sensor networks and control systems, on the other hand, it makes it disadvantageous in applications requiring large-scale data transfer (Kizilirmak, 2012).

Table 3. Comparison of IoT Based Wireless Communication Protocols

	Bluetooth	Wi-Fi	ZigBee
Frequency	2.4 GHz	2.4 GHz 5 GHz	868 MHz 915 MHz 2.4 GHz
Modulation	FHSS	QPSK OFDM QAM	DSSS BPSK O-QPSK
Range	10 metres	100 metres	10-100 metres
Data Rate	1 Mbps	11 & 54 Mbps	250 Kbps
Topology	Star and Mesh	Star and Point-to-Point	Star and Mesh
Network size	7	Depends on the number of IP addresses	64000
Power consumption	Medium	High	Low
Number of Channels	19	13	11 and 16

ZigBee Modules and Features

While some modules running on the IEEE 802.15.4 protocol contain only a receiver / transmitter chip called transceiver, a microcontroller and transceiver chips are preferred in many other modules together. By using additional amplifier circuits in some modules, the wireless communication range has been increased due to the signal strength. Generally 900 MHz Xbee products licensed in North America and 868 Mhz products licensed in Europe.

CC2530 ZigBee Module

The CC2530 is a complete System-on-Chip (SoC) solution for IEEE 802.15.4 ZigBee applications. It allows to create durable network points with very low material costs. The CC2530 combines a high performance RF transceiver chip with a 8051 microcontroller,

flash memory, 8-KB RAM memory, and many other features. CC2530 has four different flash memory options: 32/64/128/256 KB. CC2530 has different operating modes suitable for applications where low power consumption is required. The possibility of fast switching between operating modes brings low energy consumption. (Texas Instruments, 2011)

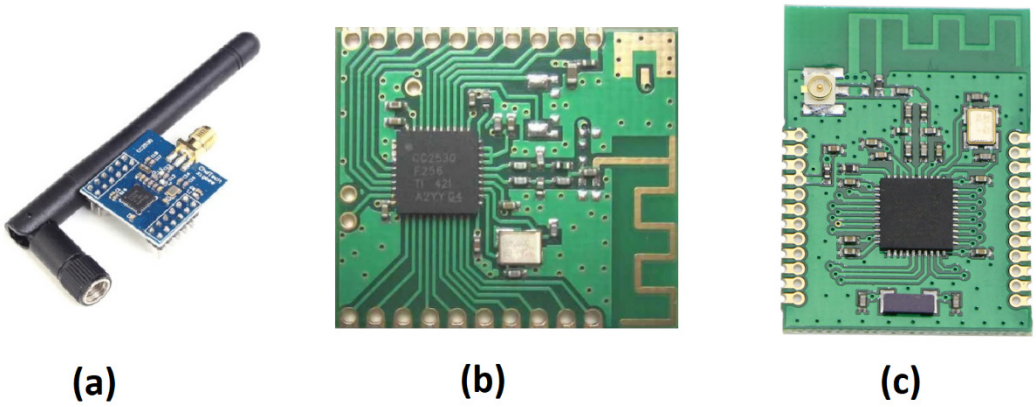

Figure 7. CC2530 Module Types, a: with SMA Antenna Connector, b: with PCB Antenna, c: with PCB Antenna and UFL Antenna Connector

There are different studies conducted indoors and outdoors using the CC2530 module. These include applications such as sound transmission systems to be used in emergency situations. (Mousavi et al., 2012)

XCore2530 ZigBee Module

XCore2530 is a CC2530 chip combined with the RXF2401 amplifier. In this way, it is used to communicate at greater distances. XCore2530 equipped with SMA antenna.

For example, in a study to detect forest fires, it was possible to use the XCore2530 module due to its long distance communication capability. (Hlaing & Aung, 2019)

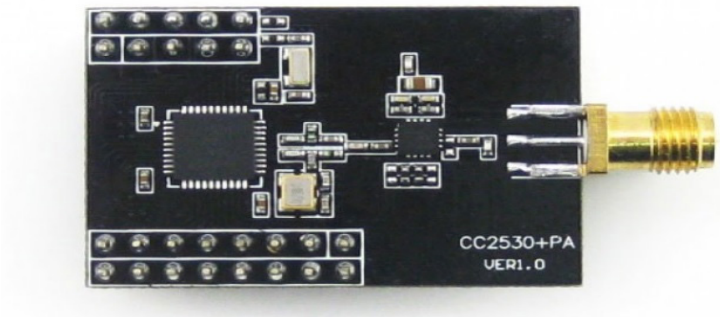

Figure 8. XCore2530 ZigBee Module

XBee

XBee modules allow the creation of complex ZigBee-based mesh networks. It provides a solid and simple communication between serial port data transfer and microcontrollers. XBee is ideal for general purpose communication applications thanks to its 2mW output power, 120 meters communication distance, internal antenna, 250 kbps data transmission and 8 digital IO pins (Ghazal & Khatib, 2015).

XBee series 1 modules can be used between two devices (P2P communications) without any configuration. In addition, series 1 modules can be used with wired serial communication without being configured with software such as XCTU. However, series 1 modules are not compatible with newer modules such as series 2, 2.5 or ZB.

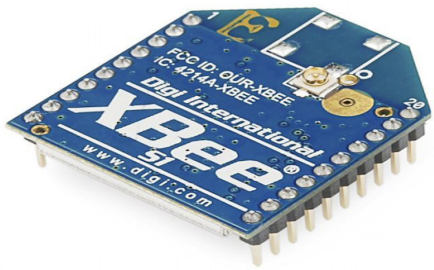

Figure 9. xBee Series 1.

XBee 2

xBee Series 2 modules need configuration even for dual (P2P) usage. Series 2 modules have better power efficiency and longer communication distance than Series 1 XBee modules.

XBee Pro

xBee Pro modules are pin compatible with a regular XBee module, so they are easy to use together or interchangeably. Some XBee Pro modules take more space than regular XBee modules. XBee Pro modules consume more power and have a longer communication distance. XBee Pro modules can be used with chip-shaped antenna, SMA antenna, cable antenna or UFL antenna like other XBee modules.

Figure 10. xBee Pro with Wire (whip) Antenna.

ZigBee Module Connections with Microcontroller Cards

CC2530 and XBee family zigBee communication modules support SPI (Serial Peripheral Interface) and UART (Universal Synchronous Asynchronous Receive Transmit) protocols. UART or RS232 standard is slower than SPI protocol and only two devices can be connected to each other at the same time. SPI protocol has a master / slave structure and more than two devices can communicate with each other.

ZigBee Module Configuration Software

There are several configuration software that support different hardware. These software allow viewing and setting of Router, coordinator and endpoint devices in the coverage area of the ZigBee hardware connected to the computer. These software also allow the arrangement of the ZigBee network topology.

XCTU

XCTU software is compatible with XBee modules from Digi Corporation and it is free of charge. It allows ZigBee modules to be set up, configured and tested. It is possible to communicate with the modules using API and AT consoles.

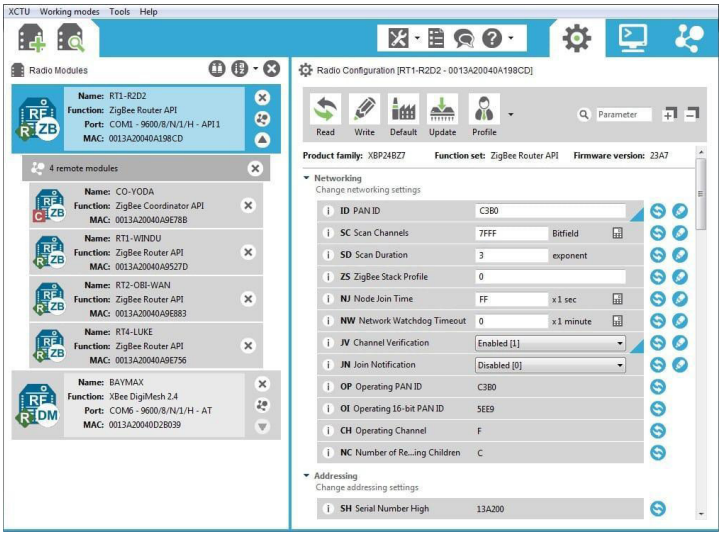

Figure 11. Sample XCTU Configuration Layout.

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