Wireless technologies

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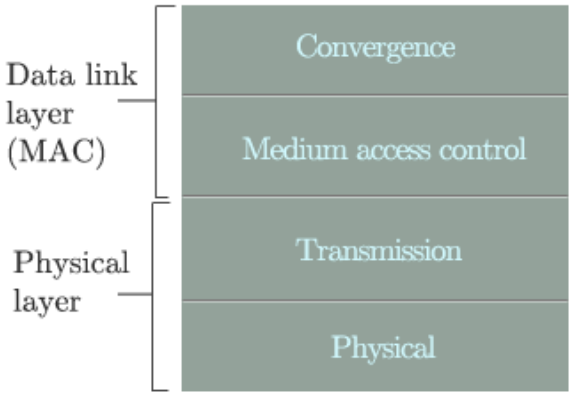
* in percentage

WiMAX

WiMAX is a wireless broadband technology, also known as worldwide interoperability for microwave access, was first developed in Norway in 1991. WiMAX could replace wired networks because it is more powerful than other technologies compared to most cable or high speed connections available. It was created to provide **last-mile** connection (a technology that is used to connect an end user to a provider), and It is a wireless, so users can connect to a WiMAX station even it was blocked by objects (e.g. buildings and trees) which is useful for users from rural area that can not be reached by wired technology or even users in cities/campus.

Protocol Architecture

WiMAX is also called IEEE 802.16 standard which is a type of wireless standards named by IEEE in 1999. It is defined only at the physical and the MAC layers. This standard can be defined into 2 aspects of interface as following :



1. Physical layer

Physical layer has jobs of encoding, decoding, transmission bits, reception bits, and preamble generation/removal. At this layer, Orthogonal Frequency Division Multiplexing (OFDM) is introduced to divide spectrum into multiple small-bandwidth sub-carriers and each sub-carrier is modulated

with a modulation scheme which could be PSK or QAM at a low symbol rate, maintaining total data rates is the same concept of single-carrier modulation schemes in the same bandwidth. Channel coding is involved convolutional coding (a type of error code) and Reed-Solomon coding. For modulations, often. Base on 802.16 in 2004(updated) and 802.16e in 2005, scalable orthogonal frequency-division multiple access (SOFDMA) is used, replaced OFDM.

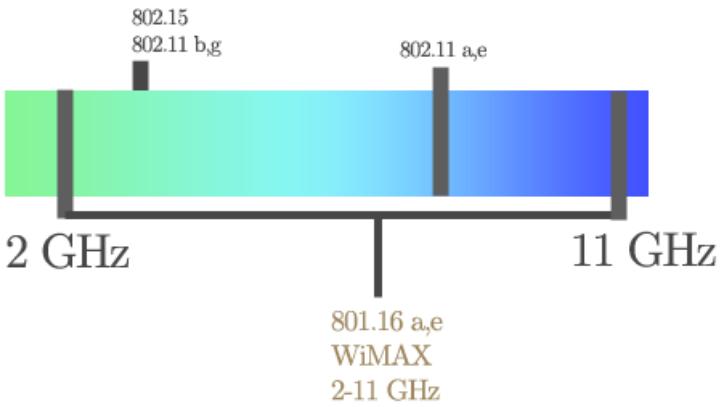
2. Medium access control layer

Medium access control layer functions are assembling data into a frame with address, disassembling frame, performing address recognition, ruling access to the transmission medium and error detection. Scheduling algorithms is used in WiMAX MAC which will give a good control Quality of service (QoS).

Data Transimission

Because WiMAX has many different standards, some standard uses different range of spectrum as following examples:

IEEE 802.16 spectrum from 10 to 66 GHz licensed.
IEEE 802.16a spectrum from 2 to 11 GHz licensed/non-licensed.
IEEE 802.16e spectrum from 2 to 6 GHz licensed bands.

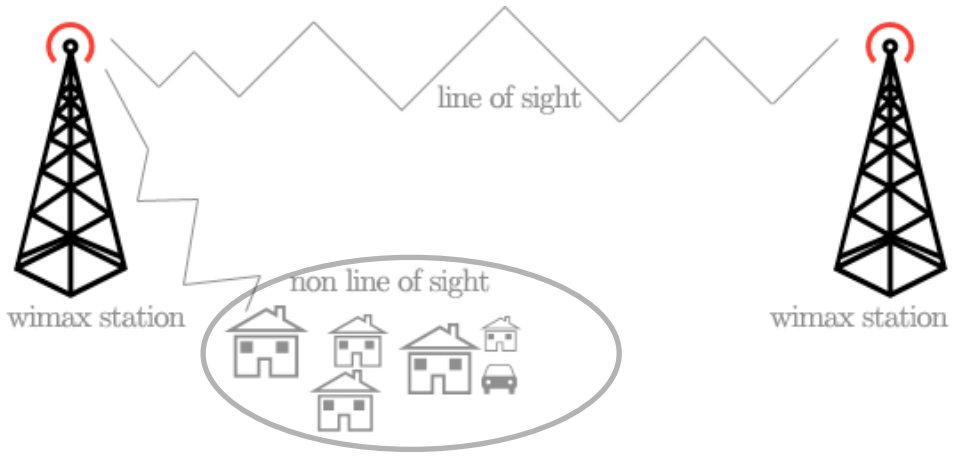


WiMAX a has spectrum between 2 to 11 GHz licensed, there is no exact value but according to the announcement of WiMAX forum, they published spectrum profiles which are 2.3 GHz, 2.5 GHz, and 3.5 GHz.

Theoretically, the maximum bandwidth of WiMAX 802.16 is 75 Mbps using 64QAM 3/4 modulation. There are many modulation technique (e.g. BPSK 1/2, QPSK 1/2, QPSK 3/4, 16-QAM 1/2) each of them gives different data rate and range.

Transmission media

WiMAX stations transmit at power of +43dBm and WiMAX mobile station transmit at +23dBm, there are different gap between base station and mobile station. Also WiMAX station uses much higher modulation orders to achieve high throughput, so it requires a much better SNR than mobile station. To make higher modulation orders on mobile station, it requires complex design in hardware.



WiMAX has maximum range of 49.8 km (31 miles) with a direct line-of -sight (fixed stations). Non-line-of-sight (NLOS) conditions will limit the range, in the 2.5 GHz and 3.5 GHz will mostly fall between 6-8 km (4-5 miles).

WiMAX consists of 2 parts which are WiMAX transmit station and WiMAX receiver. WiMAX transmit station provides coverage a large area. WiMAX receiver can be a card in desktop/laptop, a box(WiMAX Gateways) of a receiver that provides LAN, an antenna USB(WiMAX Dongles) or a WiMAX mobile.

Signal Encoding Technique

Quadrature amplitude modulation(QAM) is used widely in wireless technologies including WiMAX. QAM covers both an analog and a digital modulation scheme. QAM is a combination of Amplitude-shift keying (ASK) and Phase-shift keying (PSK).

Error

According to IEEE 802.16.1 Frame Format, Cyclic redundancy check(CRC) is used as an error detecting algorithm. CRC is one of the most common used in network, it is also called polynomial code checksum.

An example of **CRC** from Figure CRC - pick a divisor to be 11, then extend the data(13) by padding 3 of 0's (by moving the divisor to the right by one bit, there are only 3 bits for padding), in order to put FCS value which can be any number that is the value (after combining with padding data) can be divided by the divisor, the result is the transmit data. After sending the data to the destination, use divisor to divide the receive data, if it is a number then there is no error, if it is not a number then is said to be an error.

```
Input ------------>      01101          = 13
Divisor ---------->      1011           = 11
-----------------------------------------------
Data                     01101          = 13
Padding data             01101000       = 104
FCS                           110       = 6
Transmit data            01101110       = 110
-----------------------------------------------
Receive data             01110110       = 118
Divisor                  1011           = 11
Answer                   not a number!
```

Figure CRC

At physical layer, Reed–Solomon (RS) is also known as non-binary cyclic error-correcting, used as an error correction algorithm in WiMAX, was invented in 1960 by Irving Reed and Gustave Solomon at MIT Laboratory. RS is also used in DSL and electronic devices such as CDs, DVDs, and Blu-

rays, Thus, it was found in the wide ranging applications in all of digital communication and storage field.

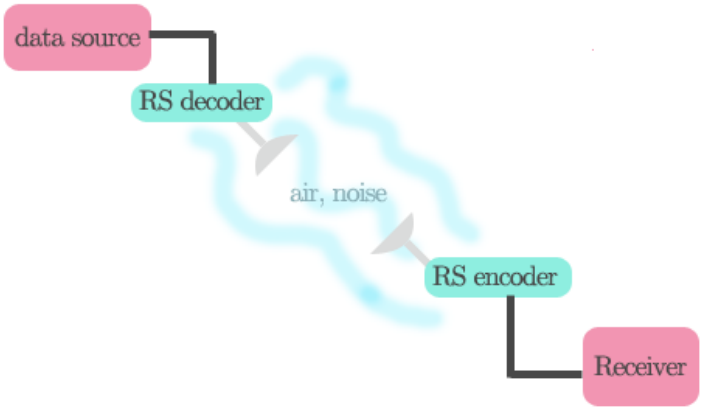


Figure 1e

Figure 1e - From the data source, the transmit data pass RS encoder then it is transmitted to RS encoder and then receiver.

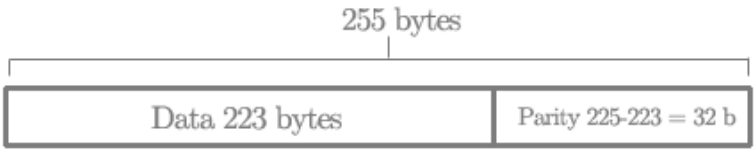


Figure 2e Breakdown of RS(255,223) codeword

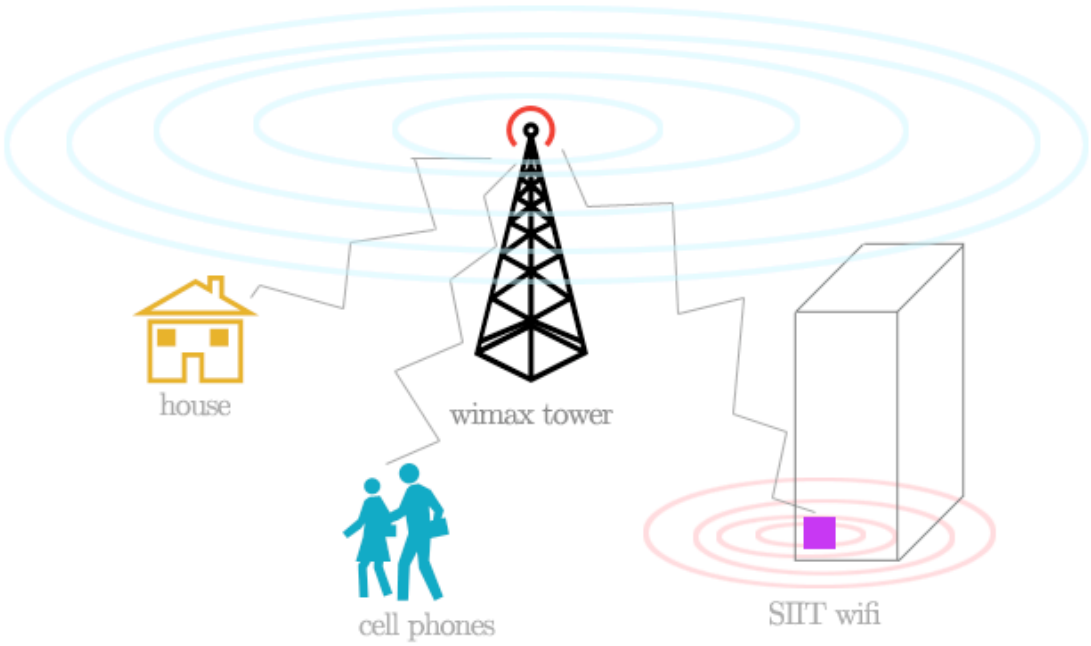
Figure 2e, The codeword can be written in form of **RS (n, k)** where n is the number of total byte and k is the number of data in byte.

Encoder - The job of RS encoder is to take k data symbols, and append n - k parity symbols to produce a code word of n symbols. The general idea is the construction of a codeword; the coefficients produced will be symbols that the generator polynomial can divide the (data+parity).

Decoder - correct errors by computing each codeword, If there is an errors, RS Decoder will find the location of its and correct it. The decoder can correct at most (n-k)/2 errors, which is 16 errors in the Figure 2e.

Example of another application over storage devices, storage devices are containing data of D1 , . . . , Dn and the storage devices are also containing checksums of C1 , . . . , Cm and checksums are defined as C1 =

F1(D1 , . . . , Dn) to Cm = Fm(D1 , . . . , Dn). Assume that Ci = Fi (D1 , . . . , Dn) = D1 ⊕ D2 ⊕ · · · ⊕ Dn. If Dj is lost, then remade from Dj = D1 ⊕ . . . Dj −1 ⊕ Dj +1 · · · ⊕ Dn ⊕ C1. If any devices fail, they can be recomputed from the another devices as well as checksums. RS is sometime required Galois fields, and Gaussian elimination.



Application

There are many applications from WiMAX technology. Because of the long rang of WiMAX, people can use internet from cell phones, laptop or even LAN/wireless network can receive signals from a WiMAX tower and share in the network. There is also a device on video broadcasts that allows TV news stations to transmit live broadcasts from a WiMAX area without using satellite and microwave trucks.

Usage

According to WiMAX map of the WiMAX forum, There are only 2 WiMAX station in Thailand which are located at Mae Fah Luang University and Bangkok(in development).

Cost

WiMAX is still quite a new wireless technology and it is being developed, so it is not easy to estimate the cost of constructing a WiMAX tower. But The approximate cost of a WiMAX base station would cost 1,600,000 THB, an UMTS base station costs 740,000 THB, and a mini station costs less than 40,000 THB(information from 2007). This is not included the cost of construction, sector antenna, and license.

For users, WiMAX pricing would cheaper than DSL, that is because it does not need wires which would help providers the cost, so they could sell it cheaper. And also, WiMAX users only need a supporting hardware or an external device to connect to a WiMAX tower.

Wireless LAN

Wireless LAN is another wireless technologies that no longer needs LAN cables to connect to the Internet.

Protocol

There two protocols in wireless networking, they are ad hoc network and infrastructure network. For ad hoc network like in the figure 1WL, these computers act as client nodes that will forward the data to other client nodes in the area. There are no access point for ad hoc network.

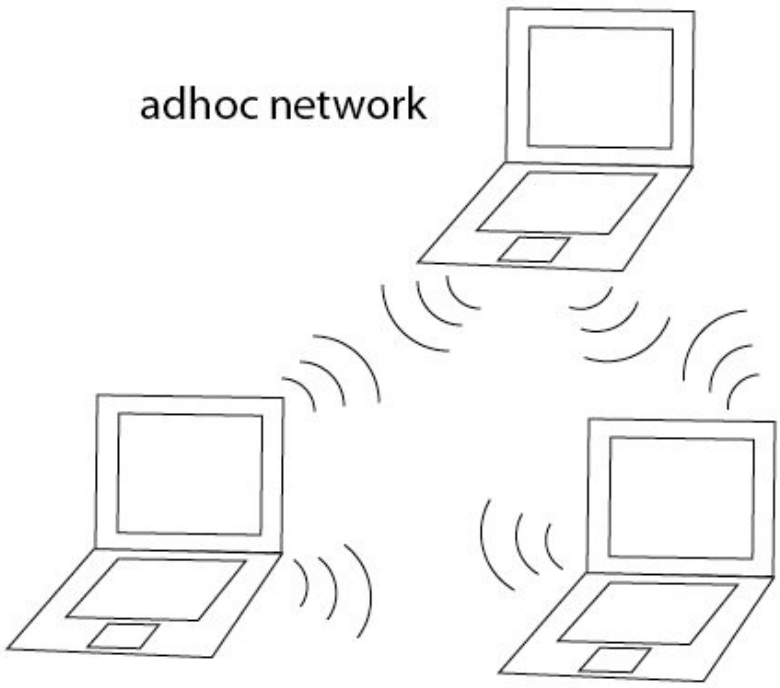


figure 1WL

For infrastructure network in the figure 2WL there are access points connect with the wired network where as access points forward data to the client computers.

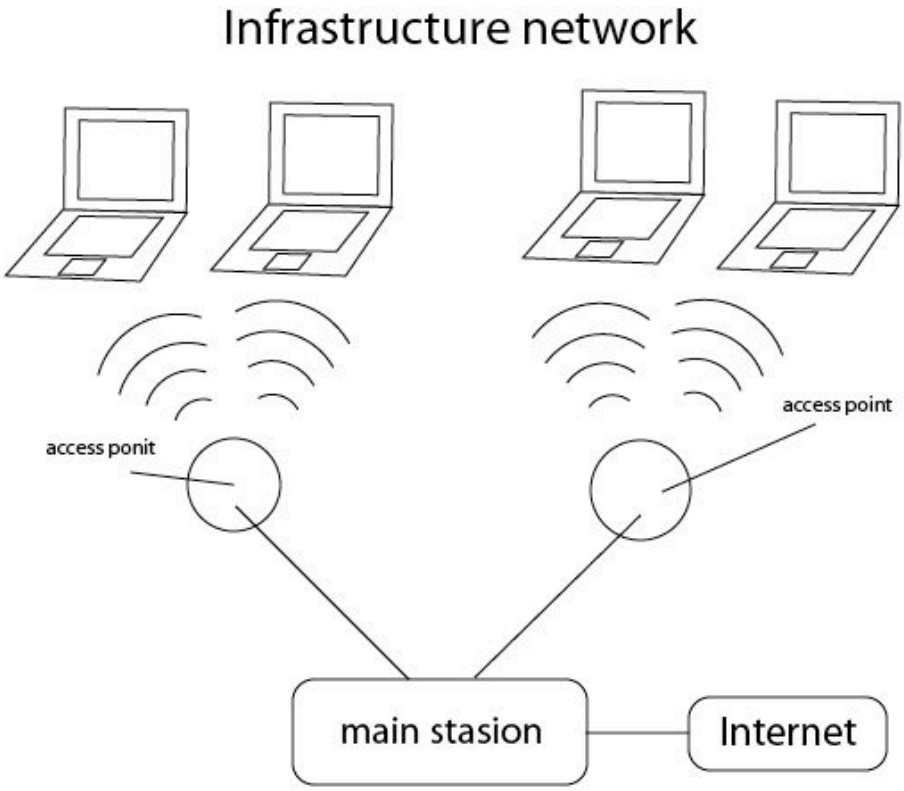
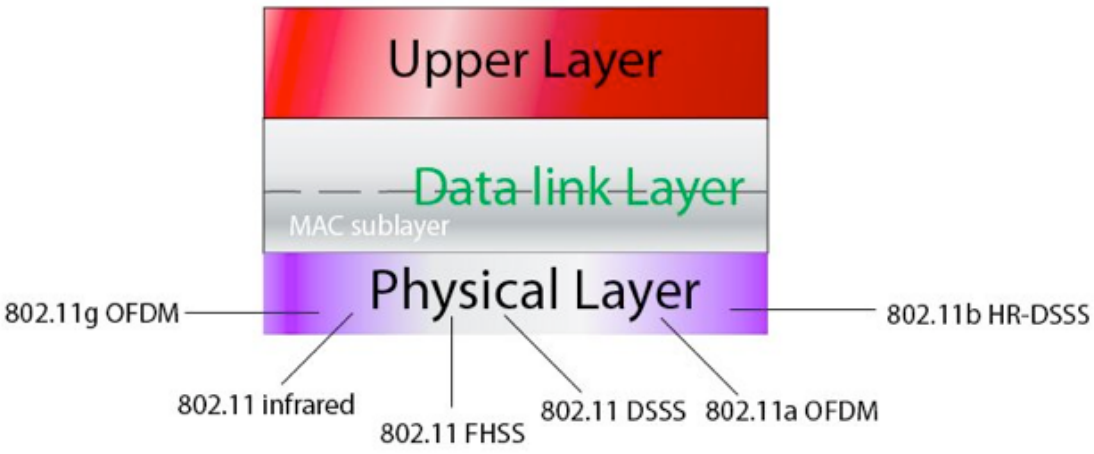


figure 2WL

Protocol architecture



Layer Stack

For layer stack, there are three layers and a sublayer. The three layers are Upper layers, Data link layer, and Physical layer. The sublayer is MAC sublayer. The data link layer will be explain in protocol part. The

components in physical layer are three 802.11 with different modulation, 802.11a,802.11b and 802.11g.

Standard

The IEEE standard organization created by the IEEE LAN/MAN Standards committee. For wireless lan the standard of wireless lan which are

1.) 802.11a
2.) 802.11b
3.) 802.11g

Data Transmission

Type	Frequency (GHz)	Spectrum
802.11a	5 GHz	unlicensed 802.11a and ISM
802.11b	2.4 GHz	unlicensed ISM
802.11g	2.4 GHz	unlicensed ISM

Frequency

1.) 802.11a have a frequency of 5GHz
2.) 802.11b has a frequency around 2.4GHz
3.) 802.11g also has a frequency around 2.4GHz

Spectrum

1.) 802.11a spectrum type is unlicensed 802.11a and ISM.
2.) 802.11b,g spectrum type is unlicensed ISM.

Where ISM comes from Industrial Scientific and Medical radio bands.

Bandwidth

802.11a has a bandwidth at 20MHz along with 802.11b, 802.11g also has a bandwidth at 40MHz.

Data rates

For 802.11a the data rate is up to maximum of 54 Mb/s and for 802.11b the data rate is up to maximum of 11 Mb/s. Then for 802.11g the data rate is up to maximum 54 Mb/s.

Type	Bandwidth	Data rates
802.11a	20 MHz	54 Mb/s
802.11b	40 MHz	11 Mb/s
802.11g	40 MHz	54 Mb/s

Transmission media

Wireless LAN used radio frequency instead of LAN cable, so that make it easier to set up the network.

Type	Transmit Power	Distance indoor	Distance outdoor
802.11a	40 mW	35 meters 115 feet	120 meters 390 feet
802.11b	100 mW	38 meters 125 feet	140 meters 460 feet
802.11g	100 mW	38 meters 125 feet	140 meters 460 feet

Transmit Power

1.) For 802.11a the maximum transmit power is 40 mW in 5 GHz frequency bands.

2.) For 802.11b the maximum transmit power is 100 mW in 2.4 GHz frequency bands.

3.) For 802.11g the maximum transmit power is 100 mW in 2.4 GHz frequency bands.

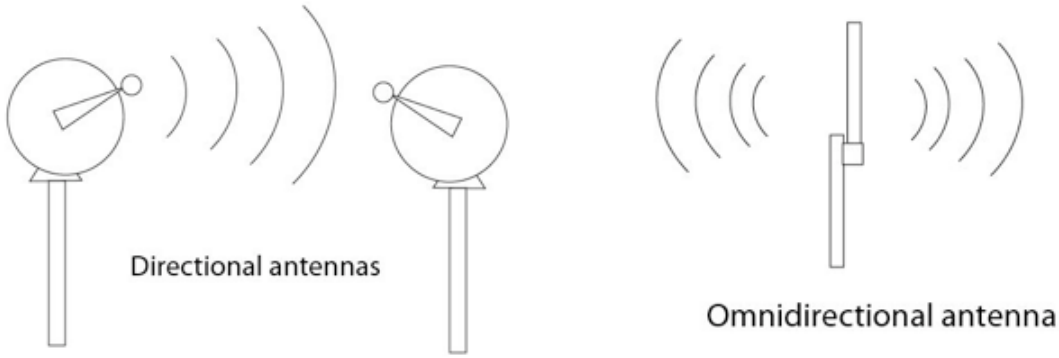
Distance

1.) For 802.11a the distance of indoor is about 35 meters or about 115 in feet for 5 GHz frequency. While the distance for outdoor is about 120 meters or about 390 in feet for 5 GHz frequency.

2.) For 802.11b the distance of indoor is about 38 meters or about 125 in feet. While the distance for outdoor is about 140 meters or about 460 in feet.

3.) For 802.11g the distance of indoor is same as the 802.11b as well as the distance of outdoor.

Antennas



Antennas have different characteristics there are directional, omnidirectional antennas. For directional antennas, directional antennas reduced the interference from other source and increase the power for transmit and received. For the omnidirectional antennas, omnidirectional antennas can used to connected multiple directional antennas outdoors, we called this as point-to-multipoint communication system. There are different type of antennas for example yagi antennas,omni antennas, and parabolic antennas.

Yagi antenna look like figure 1AWF, it has two models for 2.4GHz and 5.8GHz and used in outdoor.Yagi antenna is directional antenna.

figure 1AWF

figure 2AWF

Omni antenna look like figure 2AWF, has two models for 2.4Hz and 5.8GHz and used in both outdoor and indoor. Omni antenna is omnidirectional antenna.

Parabolic antenna look figure 3AWF, has only for 2.4GHz model and used in outdoor. Parabolic antenna is directional antenna.

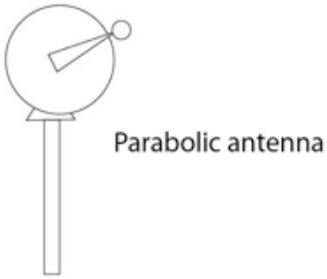


figure 3AWF

Signal Encoding Technique

The radio frequency used for wireless LAN is analog signal and here are the encoding techniques for each wireless LAN.

1.) 802.11a, 802.11g and 802.11n used OFDM (Orthogonal Frequency-Division Multiplexing) which is a encoding technique. Its work by divided radio signal or frequency into smaller smaller radio signal which can reduced the interference between signals.

2.) 802.11b used DSSS (Direct Sequence Spread Spectrum). Its work by sending the sequences of code that are called chips to the receiver. Chips rate is transferred much higher than the bandwidth.

Error

Wireless LAN use CRC (Cyclic Redundancy Check) to detected and corrected the error. And for error control, wireless LAN use FEC(Forward Error Control) using FEC there is no need to retransmit the data because FEC send a error correction code along with the data already.

Cost

802.11a is the most expensive wireless LAN, for 802.11b is the cheapest wireless LAN, and for 802.11g is more expensive than 802.11b but not expensive than 802.11a.

Based on CISCO products in each types, the overall cost for antennas are around 552 - 8,200฿. The overall cost for power supply,power injector are around 1,139 - 8,786฿. The overall cost for accessories are around 909-3,979฿. The overall cost for access points include accessories and radio modules are around 368-25,036฿. The overall cost for bridges are around 36,168฿. The overall cost for cables are around 3,301-13,352฿. The overall cost for controllers are around 84,031 - 1,040,808฿. The overall cost for controller powers are around 41,592฿. The overall cost for location appliances are around 420,613฿. And the overall cost for management software are around 98,061-168,188฿. So to set up the whole wireless LAN network would like to have the money more than 1,800,000฿.

Usage

Wireless LAN is a short distance wireless networks so Wireless LAN is likely to be use in households and small companies which don't have many buildings. If wireless are used in a large distance, it will reduce the signal strength from the access point. In Thailand wireless LAN used in many households, universities and companies. There are also WiFi hot-spots in many place in Bangkok. So Thailand most likely to use the 802.11b and 802.11g.

Application

There are some applications using the wireless LAN technologies. One of them is wireless VoIP (Voice over Internet Protocol) which is a communication device. Another are PC, Laptops, mobile phones, iPad that can used wireless LAN(WiFi).

Bluetooth

Bluetooth is a wireless technology for transferring data over short distances. Bluetooth is one of the PANs network (personal area networks). Bluetooth has high levels of security and it was created by Ericsson in 1994.

Protocol Architecture

Protocol Stack

Has 2 Types of connection

1. Asynchronous Connectionless (ACL)

ACL is used for normal data transmission, support synchronous and asynchronous connection. Multi-slot packet is used when ACL is used, Data rate will be highest at 732 Kbps in one direction and 57.6 Kbps in other direction. The master will control bandwidth of its slave, and also ACL support broadcast message too.

2. Synchronous Connection Oriented (SCO)

SCO is used for sound data transmission, support synchronous connection, circuit switch and point-to-point connection. It has data rate about 64 Kbps and SCO can be connected 3 channels at the same time.

Data Transmission

Bluetooth had frequency of 2.4 GHz (2,400 – 2,483.5 MHz) short-range radio frequency band, and data rate of 723.2 Kbps for asymmetrical Communication and 439.9 Kbps for symmetrical communication. Standard Bluetooth 1.1 Class 2 has approximately distance around 10-10m, in every directions or isotropic.

The maximum bandwidth for any single channel or frequency is 1 megabyte per second (1Mbps), while individual packets range up to 2,745 bits.

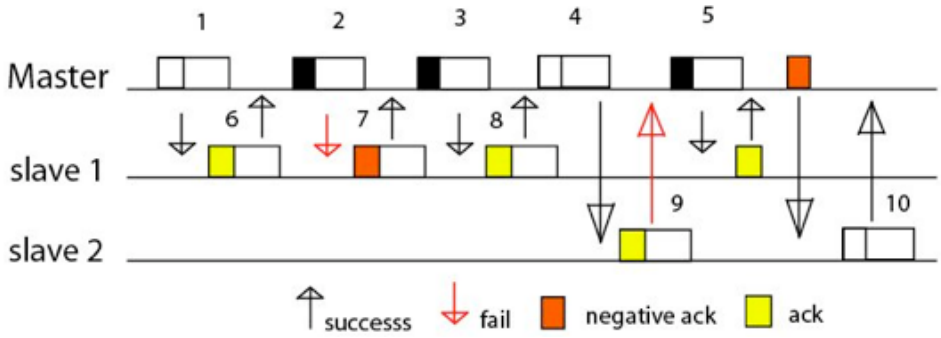
Transmission media

For transmit power, bluetooth has transmit power of -70 dBm. And the distance that bluetooth can be transmitted is 5-100 meters.

Signal Encoding Technique

Since bluetooth is a wireless network that use radio frequency, the data come in analog data. Bluetooth used GFSK (Gaussian Frequency Shifted Keying) modulation

Error



There are three error correction in bluetooth,1/3 FEC (Forward Error Control), 2/3 FEC and ARQ unnumbered scheme. For FEC, FEC used for decreasing the retransmission of data. For ARQ scheme, if the data did not reach the receiver the receiver will send the negative ACK to the sender, and the sender will retransmitted the data to the receiver. If the data transmitted successfully the sender will send the next data.

Application

Because bluetooth has short transmission range, people used bluetooth in mobile phones, GPS in the car, small talk for mobile phones, headsets, printers, also laptops and, desktop computers.

Usage

Bluetooth is a small signal transmitted device that is not expensive, but the transmitted range is short. Having highest performance about 5-10 meters. Most of bluetooth are used to connected the network between mobile phone to another mobile phone. Or connected with the computer to mobile phone, even computer connected with computer(not much). Bluetooth used to share small files like mp3 songs or pictures. Bluetooth is not the technology to replace wireless LAN technology, that is because Bluetooth had short range transmission, its main purpose is to simplify the process of connecting products in short distance in houses.

Cost

Bluetooth devices use low-cost transceiver microchips, so the cost of manufacturing Bluetooth enabled devices is relatively low. Bluetooth chips are estimated to cost around $4 to manufacture. As a result, the prices of consumer Bluetooth devices are low.

Furthermore, since Bluetooth technology operates on an unlicensed radio spectrum, there is no charge for communicating between two Bluetooth devices. That's right, it's FREE.

The only cost the consumer receives is the cost of the actual product that is enabled with Bluetooth technology. However, any use of Bluetooth technology, data, or voice, using your cell phone is part of your regular cell phone bill. There is no account or service registry associated with using Bluetooth technology.

ZigBee

ZigBee is a ad hoc network technology, has the name from communication of bees, bees fly in zig-zag form, transferring data to another place/distance for food that is searching.

Protocol Architecture

ZigBee has generate under WPAN and under standard IEEE 802.15.4, this standard is used for low-rate transmission which means using low electricity, low cost equipment and ability to control itself.

ZigBee has the standard IEEE 802.15.4 that rule in Physical layer, has 3 frequencies which are the followings :

First, 2.4 to 2.4835 GHz bit rate 250 kb/s has 16 signal ports which are port 11-26. Second, 868 to 870 MHz bit rate 20 kb/s has 1 signal port which is port 0. And third, 902 to 928 MHz bit rate 40 kb/s has 10 signal ports which are port 1-10. Moreover, the frequency 2.4-2.4835 GHz can use around the world ,but 868-870 MHz and 902-928 MHz can use in North America, Europe, Australia, and New Zealand only.

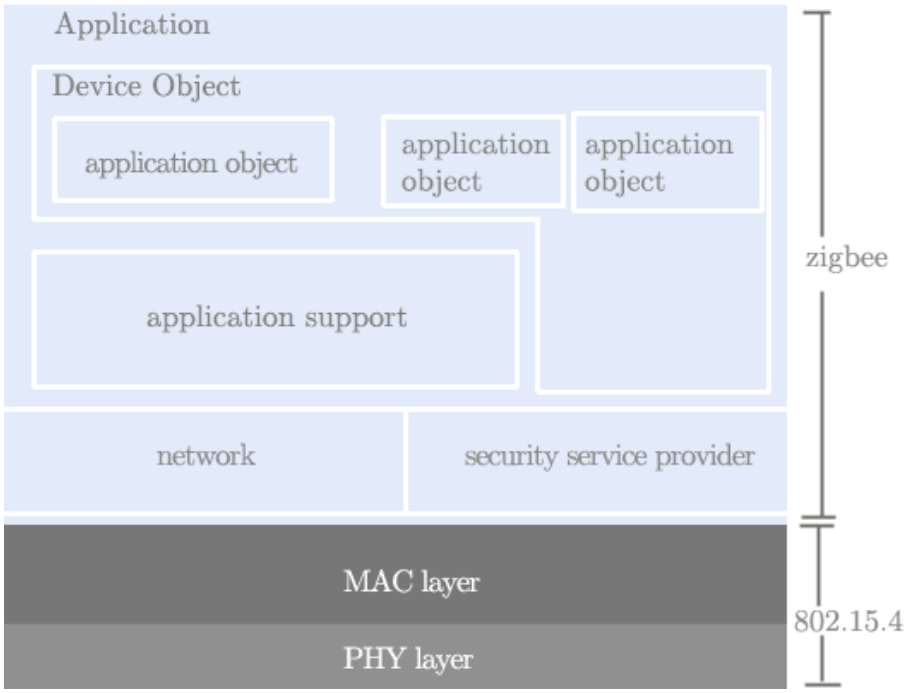
ZigBee devices has 2 types are Physical and Logical device. **Physical Device** has 2 types are

Full Function Device : FFD - using a router as a center to control transferring data from another device. It uses power from power line, can be used in any topology and also use to be connected point.

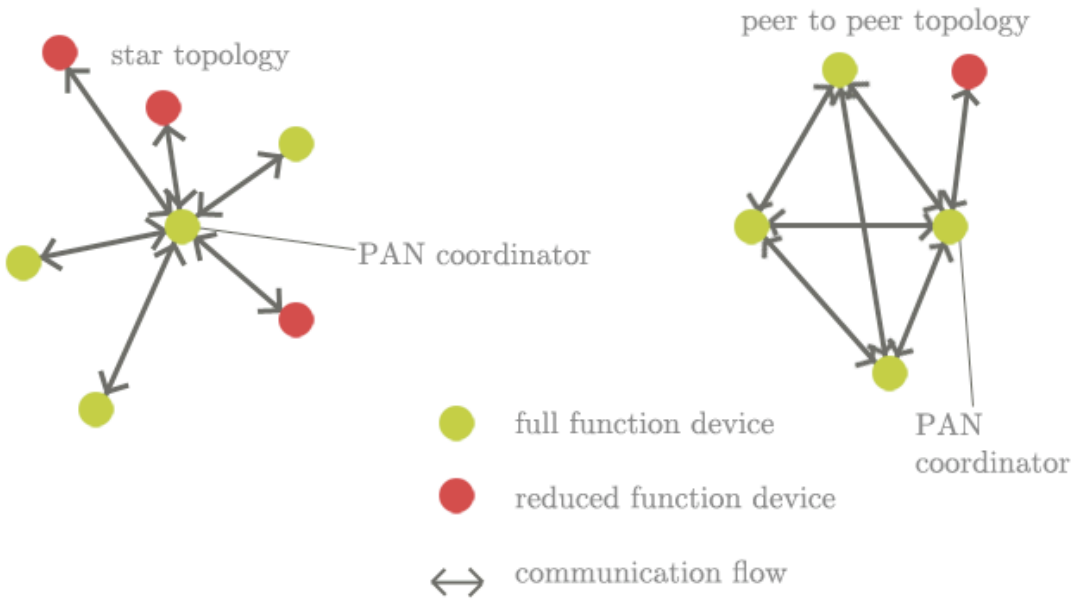
Reduced Function Device : RFD - suit for connection internal network, use power from battery, it can't transmit data to another device, best for working in STAR network.

Logical Device has 3 types of devices which are the following :

1. ZigBee Coordinators - connection point, store data in network
2. ZigBee Routers - control the flow of data between pair of node inside network
3. ZigBee End Devices -node in user side,can be RFD and FFD



ZigBee Protocol is designed for Application layer, Application support layer and Network layer only, but use MAC layer and Physical layer followed the standard of IEEE 802.15.4. The standard IEEE 802.15.4 is separated into 2 types which are star and peer to peer network.



Example of network builds

Every network will have 1FFD to control the network, called PAN coordinator and RFD will join with PAN coordinator of that network.

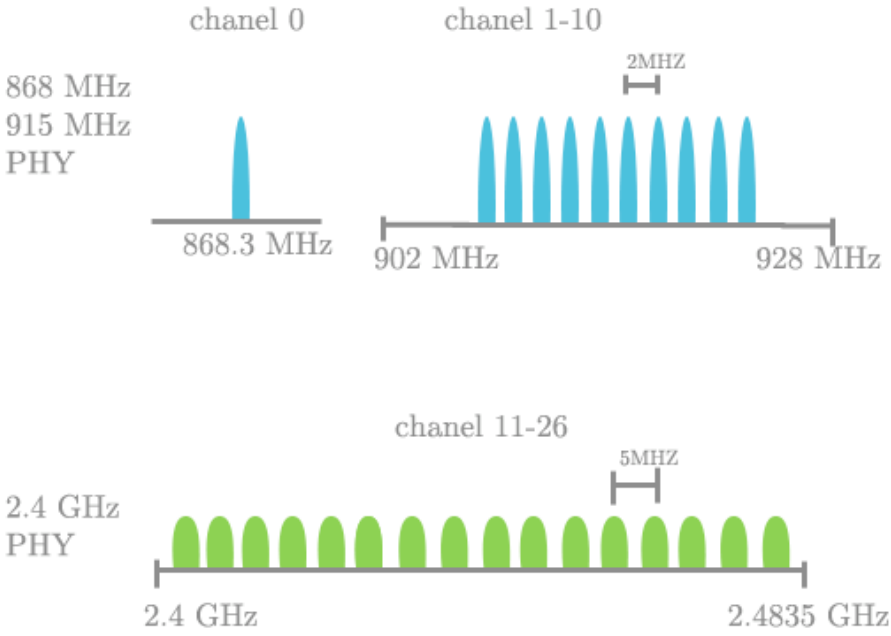
To applied ZigBee for work, the data can be separated into 3 type categories.

1. *Periodic* - data will be transfer by some period of time, Program can control transmission rate, signal detector will check and stop the flow of data, it is used for Censor and Meter Devices.
2. *Intermittent* - data will transfer will when it is being used, similar idea to electric switch.
3. *Repetitive low latency* - use in works that require low latency, communicate by separate time channel, can be used with GTS for guarantee quality of service(QoS), an example device is a wireless mouse.

Data Transmission

There are 3 frequencies that can be used in ZigBee which are

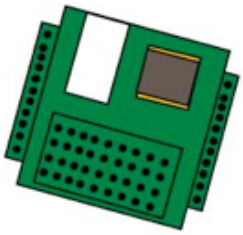
1. 2.4-2.4835 GHz bit rate 250 kb/s has 16 signal ports which are port 11-26
2. 868-870 MHz bit rate 20 kb/s has 1 signal port which are port 0
3. 902-928 MHz bit rate 40 kb/s has 10 signal ports which are port 1-10



Zigbee uses direct-sequence spread spectrum in the 2.4GHz band, with offset-quadrature phase-shift keying modulation. Data throughput rates of 250Kbps can be achieved at 2.4GHz (16 channels), 40Kbps at 915MHz (10 channels), and 20Kbps at 868MHz (1 channel).

Transmission media

Antenna-ZigBee use a chip that with or with out antenna to transmit and received data



zigbee chip

Transmission distance is expected to range from 10 to 75m, depending on power output and environmental characteristics

Signal Encoding Technique

Zigbee uses BPSK (Binary Phase Shift Keying), BPSK is a way to encode and transmit digital data, encode data in symbol. Only modulate 1bit per second. This modulation is not recommend for high data rates network.

Error

Error control for Zigbee is Embedded Forward Error Control Technique (EFECT). This technique is similar to the FEC (Forward Error Control Technique) but it is more efficient for the low data rates network like Zigbee.

Application

Zigbee can be used as a wireless network sensor to control the system for industrial or any household electric circuit remotely control. Some mobile

phones used zigbee to connected to the network. And also used for active RFIDs,and automotive.

Usage

Zigbee mostly is used in houses or small office for transmission data at low cost that does not need high speed transmission. The distance of transmission is depended on type of Zigbee module. It is a very useful instrument for testing signal transmit between 2 object (e.g. moving cars, bikes). Because of its price, Zigbee is widely used. In Thailand, Zigbee is only used for the propose of researching.

Cost

Low cost of the device, installation, and 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.

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