# ASSIGNMENT 1

## ITS232: DATA COMMUNICATION

## BY

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# Wireless LAN

## Protocol Architectures

In today world Wireless Local Area Network or WLAN is known as a communication means for transferring and transmitting data between Local Area Network and computers. By sending out radio frequency or RF and Infrared frequency through the air, this has ability to penetrate through walls or any constructions buildings without having to install any cables. Wireless network provides the same properties as the wired LAN network, however the benefits of using the wireless network is the convenience of the users enable them to getting access anywhere in the building and save installation cost.

## Connection patterns of Wireless Network

### 1.) Peer-to-Peer (ad hoc mode)



Figure 1: Peer-to-Peer (ad hoc mode) [13]

Peer to Peer is a connection done directly between computers, each computer has the same compatibility and can be run on its own as well as servicing other computers at the same time. This type of connection provides fast connectivity and is easy to install and suitable for any unconventional venues for example an outdoor meeting.

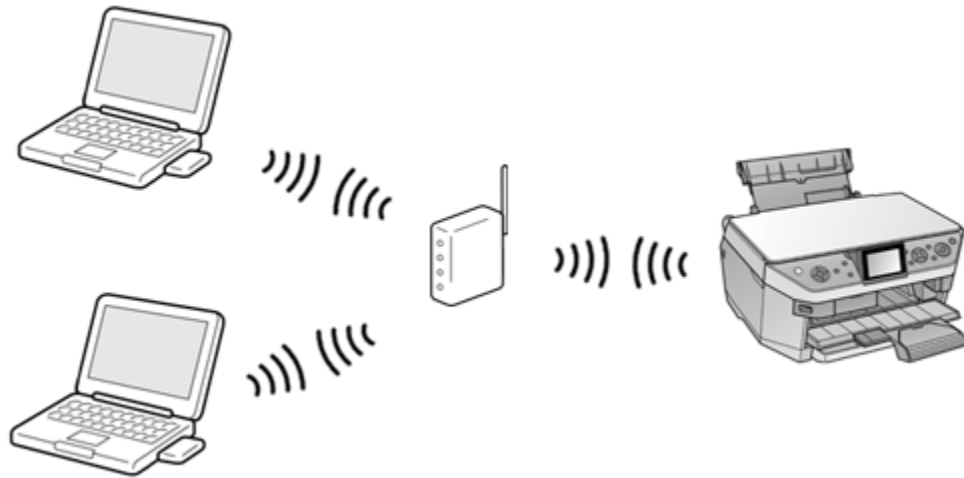## 2.) Client/Server (Infrastructure mode)



Figure 2: Client/Server (Infrastructure mode) [13]

Client/Server (Infrastructure mode) This type of connection transmitted data by using Access Point (AP) as known as Hot Spot which serves as a bridge connecting between wireless network and computers within the network or as known as Client. It will distribute radio signal to retrieve and transmit data; Each Access Point or AP can serve up to 10-50 client computers. This type of connection is suitable for the network expansion or to combine with the original LAN in offices, libraries or convention rooms to increase the efficiency of work.

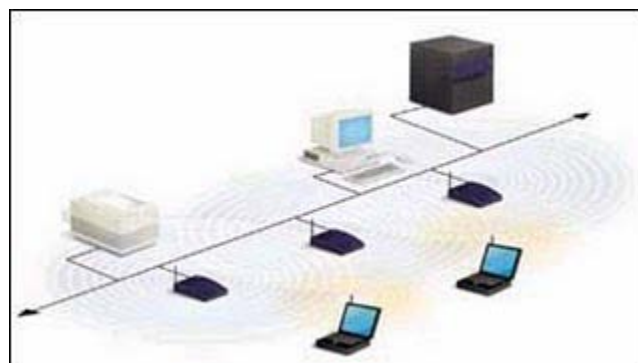## 3.) Multiple access points and roaming



Figure 3: Multiple access points and roaming [14]

Is and installation of an additional Access Point or AP to enhance the receiving of signal for a larger area to have a full coverage.
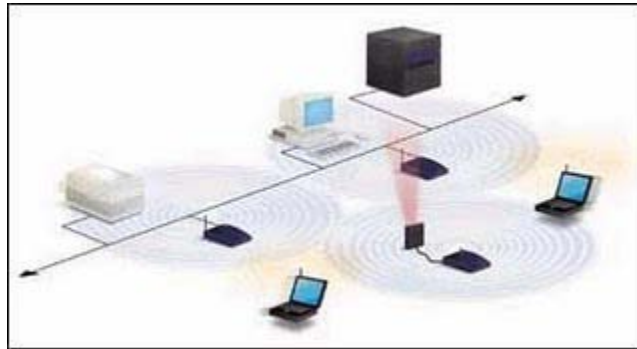
## 4.)Use of an Extension Point



Figure 4: Use of an Extension Point [14]

Has the same properties as an Access Point but does not need to be connected to a wireless network.
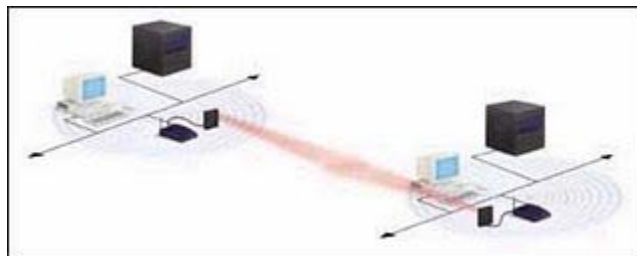
## 5.)The Use of Directional Antennas



Figure 5: The Use of Directional Antennas [14]

This type of wireless LAN used antennas to transmit and retrieve signal between distance buildings, by installing antennas at each building.
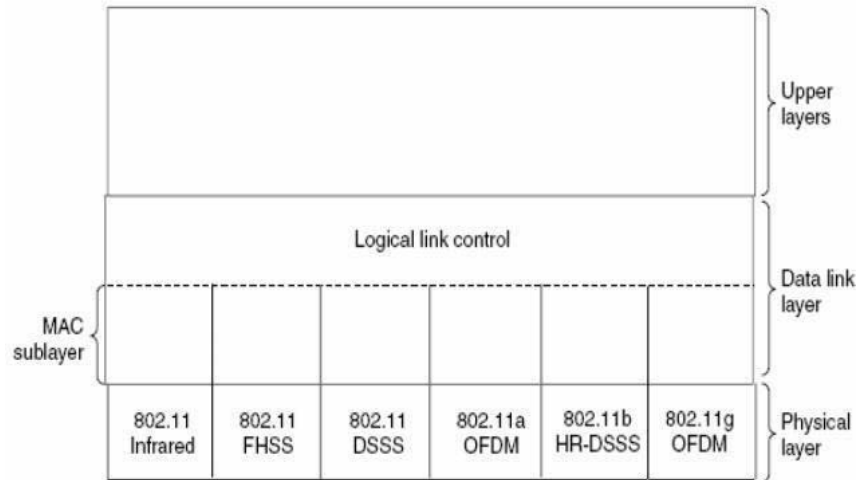
## Layered Stacks



Figure 6: Layer Stack [2]

## Protocol Stack

In a protocols stack, the low-level usually deals with the lowest protocol. The interaction with the hardware is done physically. Each higher level adds more description. User applications regularly operates with the top layers.

All 802 variants use protocols, this includes Ethernet which has a similar structure. In the figure below we see a partial view of the 802.11 protocol stack. The physical layer correspond to the OSI physical layer, however the data link layer with all the 802 protocols is spitted into two or more sub-layers. In 802.11, the Medium Access Control or MAC sub-layer determines the channel then allocates and decides what has to be transmitted next.

Above is the Logical Link Control as known as LLC sub-layer, LLC sub-layer job is to hide the differences between the different 802 variants and make them identical.

Television remote controls and the infrared method use the same technology. The other two use short-range radio by using techniques called FHSS and DSSS. These two use a part of the spectrum the 2.4-GHz ISM band which does not require licensing this also helps achieve higher bandwidth.
These bandwidths are called OFDM and HRDSSS. They operate up to 54 Mbps and 11 Mbps.
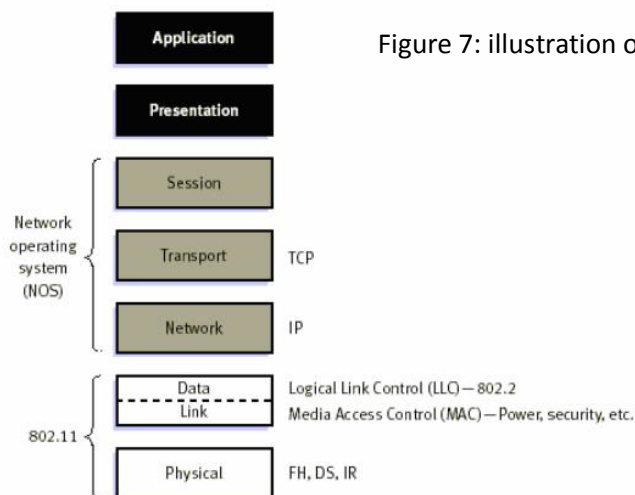


Figure 7: illustration of protocol layer in Wireless Lan [2]

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## Standard of Wireless Lan

      IEEE 802.11 is a standard for wireless communication, in 1997 there was still a limitation in technology at the time the speed was at 2 Mbps and since then it has been developing with 9 sub-parts which are a,b,c,d,e,f,g,h and i. These 9 sub-parts does not run in their original order but instead which one has finished first will reveal to the public first. Check the comparison table below.

| Standard | 802.11 | 802.11a | 802.11b | 802.11g |
|---|---|---|---|---|
| Release | July 1997 | September 1999 | September 1999 | Expected in 2002 |
| Frequency Tabs Available | 83.5 MHz | 300 MHz | 83.5 MHz | 83.5 MHz |
| Frequency Range Available (GHz) | 2.4-2.483 | 5.15-5.35 5.725-5.825 | 2.4-2.4835 | 2.4-2.4835 |
| Data rate (Mbps) | 1,2 | 6,9,12,18 24,36,48,54 | 1,2 5.5,11 | 6,9,12,18 24,36,48,54 |
| Compatibility | 802.11 | Wi-Fi5 | Wi-Fi | Wi-Fi at 11 Mbps and below |

# Data Transmission

## Spectrum

The radio frequency and infrared signals are used to transmit or exchange data.

## 1.Radio signal

1.1.) Radio is a Narrow Band Technology system, which has small frequency that can transmit frequency between 902 -928 MHz, 2.14 - 2.484MHz and 5.725 - 5.850 MHz It has low signal power with approximately 1 Miniwatt and use for exchanging data from the original point to destination  in 1 pair only.

1.2.) Spread Spectrum Technology Most of wireless network system prefer to use Spread Spectrum technique, which use wide more than Narrow Band Technology. Spread Spectrum has frequency between 902-928 MHz and 2.4-2.484 GHz period by Spread Spectrum transmit technique.
It can divide into 2 types that is Direct Sequence and Frequency-Hopping

1.3) Direct Sequence Spread Spectrum (DSSS) is use signal transmit and indicate frequency that use. This method can send data more than Narrow Band and suitable for annoy environment from radio signal.

1.4) Frequency - Hopping Spread Spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is utilized as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme.

1.5) Orthogonal Frequency Division Multiplex (OFDM) this method is used to increase data rate follow new standard of wireless LAN 802.11a and 802.11g. The transmission signal is Multiplex signal, which frequency signal is divided to many subcarriers. Every subcarrier is being perpendicular.
That wipes out signal overlay.

## 2.) Infrared signal

Infrared Technology is electromagnetic energy at a wavelength or wavelengths somewhat longer than those of red light.  The shortest-wavelength IR borders visiblered in the electromagnetic radiation spectrum the longest-wavelength IR borders radio waves.

| 802.11 Protocol | Release | Freq. (GHz) | Bandwidth (MHz) | Data rate per stream (Mbit/s) |
|---|---|---|---|---|
| - | Jun 1997 | 2.4 | 20 | 1,2 |
| A | Sep 1999 | 5 | 20 | 6, 9, 12, 18, 24, 36, 48, 54 |
| B | Sep 1999 | 2.4 | 20 | 1, 2, 5.5, 11 |
| G | Jun 2003 | 2.4 | 20 | 1, 2, 6, 9, 12, 18, 24, 36, 48, 54 |
| N | Oct 2009 | 2.4/5 | 20 | 7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2 |
| | | | 40 | 15, 30, 45, 60, 90, 120, 135, 150 |

# Transmission Media

Wireless networks do not need any cables for data transmission. Radio waves and Infrared signals are used to send communication signals through air or space. Radio waves are used for a local transmission or wireless Local Area Networks (WLANs).

These standards are specified as IEEE 802.11a with data transfer rate at 54 Mbps over 5.2GHz radio band. The 802.11b data with a transfer rate at 11 Mbps over 2.4GHz radio band and the 802.11g will provide backward compatibility with other two standards and extra security over 2.4GHz radio band.

The different radio waves is used different frequencies in a wide range of wireless communications for example AM radio uses 300 to 3000 KHz, FM radio uses 30 to 300 MHz, mobile phone uses 300 to 3000MHz and Satellite communications uses Microwaves which has radio waves frequency of more than 1 GHz. Wireless Local Area Networks uses 1 to 10GHz.

In the Wireless Local Area Networks (WLANs) uses Infrared light of 300 GHz to 400 THz, the downside of this network is that it cannot penetrate through walls and can be interfered by any sun radiations.

| Model | Frequency (GHz) | Transmit Power | |
|---|---|---|---|
| | | (mW) | (DBm) |
| 802.11b (CCK) | 2.4 | 100 | 20 |
| 802.11g (CCK \| OFDM) | 2.4 | 100 | 20 |
| 802.11a (OFDM) | 5 | 40 | 17 |

**802.11a The maximum power level for a 4.9 GHz (US Only, Public Safety) radio is 40 mW
**Complementary Code Keying (CCK)** is supported by 802.11b and 802.11g devices Orthogonal **Frequency Division Multiplexing (OFDM)** is supported by 802.11g and 802.11a devices.

## Range of connection Wireless LAN

### Indoor

1. 50 Meter approximately speed 11 Mbps
2. 80 Meter approximately speed 5.5 Mbps
3. 120 Meter approximately speed 2 Mbps
4. 150 Meter approximately speed 1 Mbps

### Outdoor

1. 250 Meter approximately speed 11 Mbps
2. 350 Meter approximately speed 5.5 Mbps
3. 400 Meter approximately speed 2 Mbps
4. 500 Meter approximately speed 1 Mbps

# Antenna

Job of antenna is change data in form of electric data into electromagnetic wave. That export from transmitter. Other job is receiving signal from another wireless device and change data back to original form.

## Omni directional antenna



Figure 8: Omni directional antenna [15]

Omni-directional wireless antennas are used as access point antennas.
Wireless LAN / WISP Omni antennas are totally enclosed. These type of antennas are designed to be used as a hub antenna or Access Point Antenna in a Point-to-Multipoint WLAN system. Omni Antennas have a nominal VSWR of 1.5:1 and are less than 2:1 over the entire 2400-2500 MHz frequency band. Omni directional has ranges from 9.5 dBi down to 5 dBi. The 9.5 dBi uses an elevated center-feed to produce an elevation pattern with very little "squint" or beam-tilt. The 7.5 dBi uses an end-feed to produce a downward beam-tilt with around 4 degrees.

## Yagi antenna



Figure 9: Yagi antenna [16]

Yagi Antennas work very well as a short-range wireless bridge or a low cost CPE solution. Yagi antennas are totally enclosed in radomes for both environmental protection and style. Wireless Yagi Antennas are designed to be used as a bridge wireless antennas between two networks, point to point communications or Wireless ISP CPE antennas. The Yagi Antennas have a nominal VSWR of 1.5:1 and are less than 2:1 over the 2.4 GHz frequency band. The directive gain ranges from 13.5 dBi down to 8.0 dBi.

## Parabolic antenna



Figure 10: Parabolic antenna [17]

Parabolic dish antenna maximizes distances within a bridge environment. The parabolic dish antenna is also a great CPE unit for customers who are a greater distance from an access point. Wireless LAN / WISP parabolic dish antennas have a totally enclosed feed assembly and an aluminum parabolic reflector suitable for any outdoor environment. Parabolic dish antennas are designed to be used as a bridge antenna between two networks or for point-to-point communications. Nominal VSWR is 1.5:1 and they have less than 2:1 over the entire 2400-2500 MHz frequency band. Directive gain ranges from 24 dBi down to 20 dBi. These parabolic dish antennas feature a rugged mount which offers 20 degree fine adjustment for both horizontal and vertical planes. Parabolic dish antennas are provided with hardware for mast mounting and are available in either vertical or horizontal polarization. Multipack shipping boxes are available in some models.

## Distance

The distance over which RF waves can communicate is a function of product design (including transmitted power and receiver design) and the propagation path, especially in indoor environments. Interactions with typical building objects, including walls, metal, and even people, can affect how energy propagates, and thus what range and coverage a particular system achieves. Most wireless LAN systems use RF because radio waves can penetrate many indoor walls and surfaces. The range (or radius of coverage) for typical WLAN systems varies from under 100 feet to more than 500 feet. Coverage can be extended, and true freedom of mobility via roaming, provided through microcells.

# Signal Encoding

## Techniques for Wireless LAN

**1.) Orthogonal frequency division multiplexing (OFDM)**

The resilience to severe channel conditions can be further enhanced if information about the channel is sent over a return-channel. Based on this feedback information, adaptive modulation, channel coding and power allocation may be applied across all sub-carriers, or individually to each sub-carrier. In the latter case, if a particular range of frequencies suffers from interference or attenuation, the carriers within that range can be disabled or made to run slower by applying more robust modulation or error coding to those sub-carriers. (802.11a, 802.11g and 802.11n are usesd)

**2.) Direct Sequence Spread Spectrum (DSSS)**

Direct-sequence spread-spectrum transmissions multiply the data being transmitted by a "noise" signal. This noise signal is a pseudorandom sequence of 1 and −1 values, at a frequency much higher than that of the original signal, thereby spreading the energy of the original signal into a much wider band.

For de-spreading to work correctly, the transmit and receive sequences must be synchronized. This requires the receiver to synchronize its sequence with the transmitter's sequence via some sort of timing search process.

In contrast, frequency-hopping spread spectrum pseudo-randomly re-tunes the carrier, instead of adding pseudo-random noise to the data, which results in a uniform frequency distribution whose width is determined by the output range of the pseudo-random number generator (802.11b used)

# Errors

1.) **Low-density parity-check (LDPC)**

Low-density parity-check (LDPC) codes are a class of recently re-discovered highly efficient linear block codes. They can provide performance very close to the channel capacity using an iterated soft-decision decoding approach and at linear time complexity in terms of their block length.

2.) **Forward error correction (FEC)**

FEC processing often occurs in the early stages of digital processing after a signal is first received. That is, FEC circuits are often an integral part of the analog-to-digital conversion process and also involving digital modulation and demodulation or line coding and decoding. Many FEC coders can also generate a bit-error rate (BER) signal which can be used as feedback to fine-tune the analog receiving electronics.

## Applications for Wireless LANs

Wireless LAN is popular use in the modern world. The Most of people know about wireless LAN in term of "Wi-Fi".

-In hospital they have many patients therefore the faster way to get information is wireless LAN. Wireless LAN is Help the doctor to know about the patient, Easy to collect history of patient.

-In university they have many students. Wireless LAN is available for student access the information of library, course introduction, student timetable, play internet (Wi-Fi) and download Lecture Sheet.

- Trade show and branch office workers minimize setup requirements by installing preconfigured wireless LANs needing no local MIS support.

- Warehouse workers use wireless LANs to exchange information with central databases

## Usage

For Thailand be interested in wireless LAN technology because it convenient to use in office building and department store. They call WI-FI or Hot-spots that available service everywhere. Wireless LAN technology is not necessary to use cable wire that reduces cost.
For big building or office can use wireless LAN everywhere in range of signal. Bad thing of Wireless Lan is can use in small area and signal easy to annoying

## Cost

A wireless LAN implementation includes both infrastructure costs for the wireless access points and user costs for the wireless LAN adapters. Infrastructure costs depend primarily on the number of access points deployed; access points range in price from 2,000 to 10,000 Bath. The number of access points typically depends on the required coverage region. The cost of installing and maintaining a wired LAN for two reasons. First, a WLAN eliminates the direct costs of cabling and the labor associated with installing and repairing it. Second, because WLANs simplify moves, adds, and changes, they reduce the indirect costs of user downtime and administrative overhead.

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# WiMAX

Worldwide Interoperability of Microwave Access (WiMAX) is a Wireless Metropolitan Area Network (WMAN). WMAN is a wireless communication network which covers a geographical area such as town, city, or suburb. It is an emerging technology which has been researched on for years but never had been realized to reality due to costly construction price.

## Protocol

WiMAX contains two major layers which are Open System Interconnect (OSi) Data Link Layer, and OSi Physical Layer. These two major layers have sublayers which are Convergence Layer, MAC Layer, (for OSi Data Link Layer) and Transmission Layer, Physical Layer (for OSi Physical Layer).
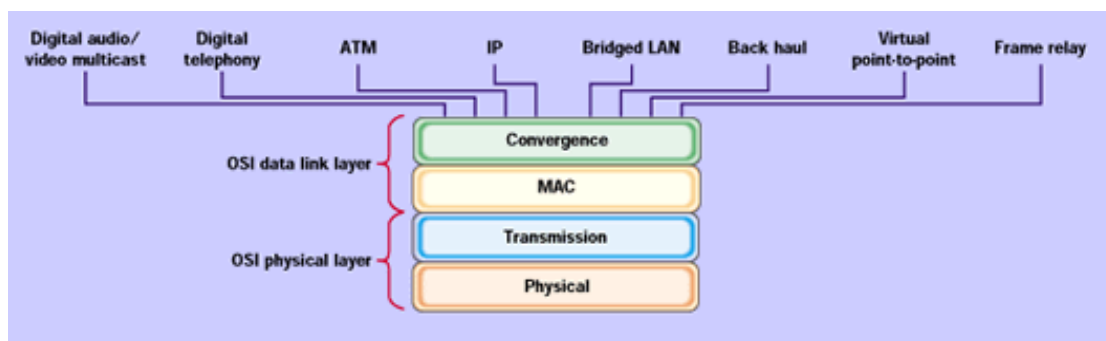


Figure 1: illustration of protocol layer in WiMAX [1]

The convergence layer adjusts the communication between the higher level protocol (such as application layer, port layer) and the lower level protocol. It also reduces redundant data which were added to the data packet by higher level protocols. Sometime this layer is considered as a sublayer in the MAC layer. The MAC layer has six different functions which are listed below:

1. Channel Access Mechanism

The MAC address controls bandwidth allocation to each user that accesses the network. The size of allocation depends on the request of each user.

2. Quality of Service

The WiMAX QoS was based from DOCSIS QoS. Uplink and Downlink are controlled by the base station. The Mobile station made a unidirectional logical link with the base station. It also controls the traffic rate of each mobile stations.

3. Power Saving

Since the WiMAX technology does not limit to only stationary devices, power saving for mobile device is necessary. The power consumed during active mode must be different from sleep mode or inactive mode.

4. Mobility Support

The connection to the WiMAX antenna should be stabilized even if the device is stable or moving. The maximum speed that a certain WiMAX device can stay connected to the network is approximately 100 [6] to 120 km/s [7].

5. Security Functions

Since the wifi is faulty in security, the IEEE wants to improve the security for users in WiMAX. Security functions such as username/password, digital certificates, smart cards, and three way handshake are implemented in WiMAX to increase security.

6. Multicast and Broadcast Service

Multicast and Broadcast Service is a technology to send multimedia data to many users at the same time. There are plans on implementing this function but no work had been done [8] on it thus some source state that the MAC layer has only 5 functions without the Multicast and Broadcast Service.


The standard which is being used for WiMAX is IEEE 802.16. There is an organization call WiMAX forum controlling the standard for WiMAX standards.


## Data Transmission

Since the IEEE 802.16 standards were set for WMAN, there has been an improvement from time to time. The most modern standard for IEEE 802.16 is the standard set in the year 2005 thus the standard was called IEEE 802.16-2005. WiMAX follows this standard which could prove that the basic data of IEEE 802.16-2005 is also t data for WiMAX. The chart below contains the basic information of IEEE 802.16-2005

|  | Frequency | Data rate (IEEE 802.16) |
|---|---|---|
| Fixed | 2 – 11 GHz | 1 – 75 Mbps |
| Mobile | 2 – 6 GHz | 1 – 75 Mbps |


According to an experiment done by a company call WiLAN at 160 km/h WiMAX was transferring at 20 Mbps. At 80 km/h WiMAX was transferring at 18 Mbps. [10]

The range and frequency could vary depending on only one factor which is the line of sight. If the WiMAX tower has no direct path to the station then it is called non-line of sight service, but if the tower has a fixed dish antenna pointing towards it then it is called line of sight service. The table below shows the different aspect of line of sight and non-line of sight service.

| Service | Frequency | Range |
|---|---|---|
| Line of sight | 2 – 11 GHz | 48.3 km (radius) |
| Non-line of sight | Up to 66 GHz | 6.5 – 9.7 km (radius) |

# Transmission Media

There are three types of WiMAX antenna: omnidirectional, sector, and panel. Omnidirectional antennas broadcast WiMAX signal 360 degrees around the antenna but the drawback of range and signal strength are great due to high power consumption to broadcast 360 degrees. Sector antennas broadcast signal in selected degrees (ie.: 60 / 90 / 120 degrees). The range and signal strength are better compare to omnidirectional antennas. Panel antennas are for point to point application. Its range are the widest compare to omnidirectional and sector antennas.
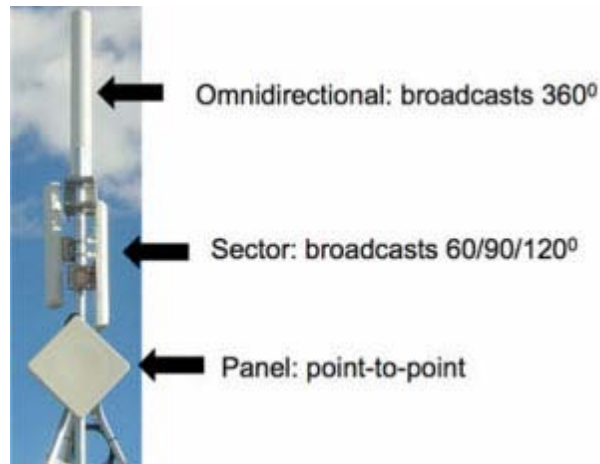


Figure 2: Omnidirectional, sector, and panel antennas [11]

| Type | Model | Size (mm) | Frequency(MHz) | Gain (dBi) | Max power(W) |
|---|---|---|---|---|---|
| Omnidirectional | BBT-Q3505BL | 35 X 450 | 3300 - 3800 | 5 | 50 |
| Omnidirectional | BBT-Q2515BL | 35 X 1350 | 2300 - 2700 | 15 | 50 |
| Sector | BBT-D3518DB | 750X163X63 | 3300 - 3800 | 18 | 400 |
| Sector | BBT-D2518DB | 975X163X63 | 2300 - 2700 | 18 | 400 |
| Panel | BBT-D3521DB | 450X450X35 | 3300 - 3800 | 21 | 50 |
| Panel | BBT-D2518DB-22 | 385X385X29 | 2300 - 2700 | 18 | 50 |

There are two types of subscriber stations for end users which are outdoor receivers and indoor receivers. Outdoor receivers perform better than indoor receivers since indoor receivers had to receive signal through concrete walls and glass windows. The received power can be calculated using the following formula.

$P_{rx} = P_{tx} + G_{tx} – A_{pl} + G_{rx} – A_m$

Where $P_{rx}$ = received power (dBm)

$P_{tx}$ = transmitter output power (dBm)

$G_{tx}$ = transmitter antenna gain (dBi)

$G_{rx}$ = receiver antenna gain (dBi)

$A_{pl}$ = path loss (dB)

## Signal Encoding Technique

Orthogonal frequency division multiplexing (OFDM) is a technique that split the signal into several signals at different frequencies. This prevents devices that received these signals will be able to only demodulate the frequency that belongs to the device. This also speeds up the receiving process since the device with a certain frequency would not receive a frequency that is not its own.

## Error

Errors are unavoidable in any system. It is up to developers to manage how to detect these errors and correct them. The error detection technique used is forward error correction where data received is a code bits for actual data. If there were errors with the data sent then the receiver will tries to correct it. If the receiver can not determine the correct data then it sends an automatic repeat request (ARQ) to the sender to make it retransmit the data.

## Application

A WiMAX tower is set by an internet service provider (ISP). The towers are set to cover geographical areas that the ISP wants. Each tower connects to each other. Users connect to a WiMAX tower with a WiMAX station or by a device custom for accessing WiMAX network.
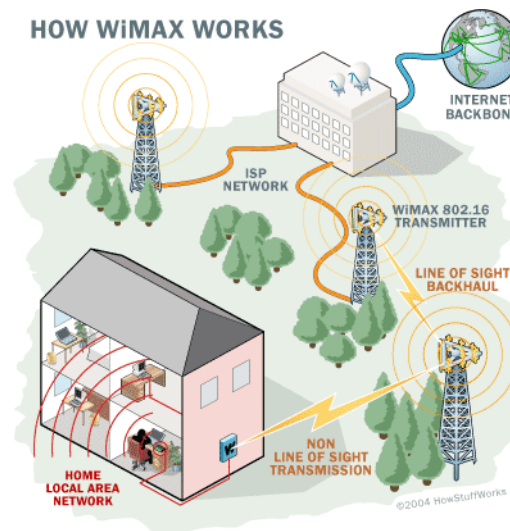


Figure 3: How WiMAX works [3]

WiMAX is design for user's mobility. Users can use a device which has an internet connect as fast as a wireless LAN at any place at any time with WiMAX. The downfall of this technology is there are no erected towers which are compatible with WiMAX signal thus companies which want to provide WiMAX needs to construct new towers for WiMAX. On the other hand, users are required to have a device which can receive WiMAX signals from the tower. Users, which are common citizens, were not ready to switch to a new unknown technology causing WiMAX to fail miserably at the implementation level.

## Usage

Since Thailand did not purchase the license of WiMAX, many companies decided not implement this product until a license is purchase. The latest news is in June 11, 2008 [15], True Corporation has conduct a WiMAX trial with one of the major WiMAX leaders, Alcatel-Lucent. Other companies, such as Motorola [16], are also interested in implementing WiMAX but it was a no-go due to no license available in Thailand. Phuket waits for Thailand to completely purchase the license and allow commercial use of WiMAX to construct WiMAX all over the island [18]. The only place in Thailand that has setup WiMAX for experimental use is Mae Fah Luang University [19].

Indonesia and Vietnam have already construct WiMAX towers in their country and might be able to cover the whole country soon. Other countries are racing to make WiMAX coverage as wide as possible to cover the whole country but no country had coverage over the whole country yet [23].

## Cost

The initial cost of a WiMAX system is approximately 1.3 billion dollars. A base station cost 15,000 dollars [24]. There are low cost promotions such as AusTex's Get One: On-The-Go plan where an user can connect to the network anywhere for 40 dollars per month [25] or home internet for only 30 dollars per month [26]. A single WiMAX tower can cost up to 125,000 dollars per tower.

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# Bluetooth

Bluetooth is a technology for short distance data exchange. It was created by Erricsson in 1994. Bluetooth are very common as a wireless communication to devices such as smart phones.

## Protocol

Bluetooth protocols are divided into core protocol, link manager protocol, cable replacement protocol, telephony control protocol, and adopted protocol. These protocol are being manage by Bluetooth SIG
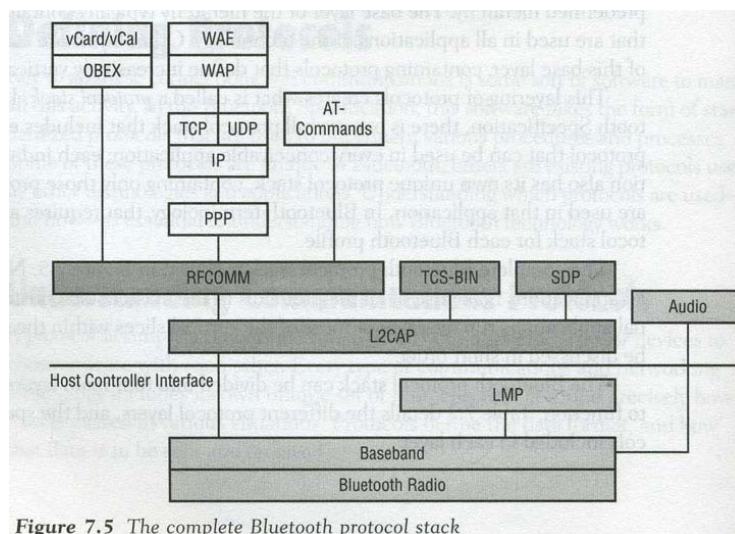


Figure 7.5 *The complete Bluetooth protocol stack*

Figure 1: Bluetooth protocol stack [1]

### Core Protocol

The core protocols are specially created protocol for Bluetooth usage. These protocol consist of baseband, link manager protocol (LMP), logical link control and adoption protocol (L2CAP), and service discovery protocol (SDP). Baseband enables physical link between two Bluetooth devices while LMP is responsible for setting up links between two or more Bluetooth devices. L2CAP transfer data from upper protocols to and from the baseband. SDP finds Bluetooth signals and recognize them as Bluetooth devices.

### Cable Replacement Protocol

There is only one protocol in the cable replacement protocol, RFCOMM. RFCOMM emulates an RS-232 serial connection between two devices. It enables the control of an emulation of RS-232 control and data signal over Bluetooth.

Telephony Control Protocols

Telephony control protocol handles voice and data from Bluetooth devices to enable a Bluetooth device to act like a telephone or a modem. Telephony control protocol consists of telephone control specification (TCS-BIN) and AT commands.

Adopted Protocols

Adopted protocols are established protocols in other industries. These protocols include PPP, TCP/IP/UDP, OBEX, IrMC and so many others.

## Data Transmission

Bluetooth devices are for short range transmission. They usually are for audio transmission for hand-free devices. The data rate needs to be high to transmit audio fluently while the range is wide enough for users to use.

| Data rate | Power | Range | Frequency |
|-----------|-------|-------|-----------|
| 1 Mbps | ~2.5 mW | 10 – 30 feet | 2.4 – 2.485 GHz |

The frequency 2.4 GHz are unlicensed in most countries.

## Transmission Media

Bluetooth devices usually contains omnidirectional antenna since there is no need for specific path for Bluetooth signal. The data of different models of Bluetooth antenna from Global sources are shown below [6].

| Model | Frequency | Return Loss | Gain | Power |
|-------|-----------|-------------|------|-------|
| OA-232708 | 2300 – 2700 MHz | -10 dB | 8 dBi | 50 W |
| TQX-2400LL | 2400 – 2483 MHz | - | 2 dBi | 50 W |

## Signal Encoding Technique

Bluetooth uses Gaussian Frequency Shift Keying (GFSK). It is a technique that gives a binary 1 when the frequency received is positive while the binary 0 is negative frequency.

## Error

There are three error correction technique Bluetooth uses 1/3 rate Forward Error Correction (FEC), 2/3 rate FEC, and ARQ unnumbered scheme.

## Application

The most common application of Bluetooth is hand-free application where users are able to put an ear piece into their ear links the device directly to a Bluetooth enabled phone to call someone. Another application is connecting an external device, such as a phone, to a personal computer by Bluetooth to transfer files to or from the external device. There are other applications but they are not as popular as the two applications mentioned above.

## Usage

Bluetooth are commonly used everywhere. It has even became mandatory to put a Bluetooth network card into laptops and PCs. Smart phones now all have Bluetooth connection available to connect to PCs to transfer files.

## Cost

The approximate minimum cost is 4 dollars to manufacture [7]. The minimum cost for end users are the cost of a device such as a smart phone with a hand-free device which could total up to approximately 210 dollars.

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# Zigbee

ZigBee is a technology built on top of the IEEE standard, addressing remote monitoring and control for sensory network applications. This standard was created by an organization known as the ZigBee Alliance, which is composed of a large number of companies and industry leaders striving to enable such control devices. It focuses on radio-frequency applications using low-power, short-range digital radios, low data rate and secure networking, based on the standard organization IEEE standard 802.15.4-2003 which is for wireless personal area networks or WPAN specifying low data rate, low power consumption, low complexity and low cost wireless systems operating in unlicensed RF domain, among other technologies. It is formally known as PURLnet, RF-Lite, Firefly, and HomeRF Lite. [1]

## Protocol Architecture

The ZigBee provides routing and multi-hop functions to the packet-based radio protocol. Its protocol layers are based on the International Standards Organization(ISO) and Open System Interconnect(OSI) basic reference model.  It implements only the layers that are essential for low-power, low-data-rate wireless networking(Physical layer and media access control layer).   These figures 1 and 2 below show the simple structure of OSI 7 layer model and the stack architecture of ZigBee, respectively.
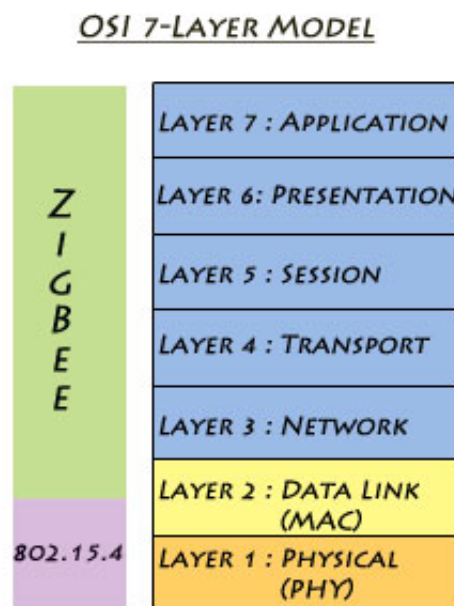


Figure 1: OSI seven layers

As shown in the figure 1, the stack layers defined by the ZigBee specification are the network, transport, session, presentation and application framework layers. The ZigBee stack is loosely based on the OSI 7-layer model. It implements only the functionality that is required in the intended markets. While, the physical or PHY layer accommodates high levels of integration by using direct sequence to permit simplicity in the analog circuitry and enable cheaper implementations. While, the media access control or MAC layer permits the usage of several topologies without introducing complexity and is designed to work with a large number of devices.
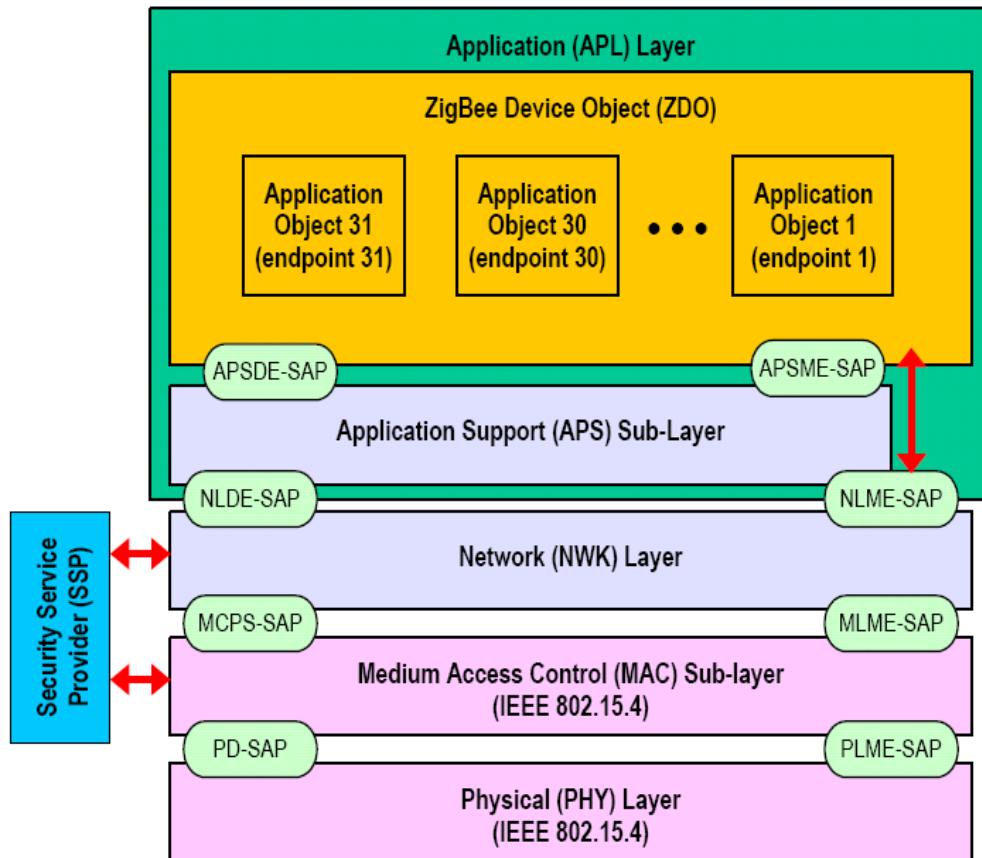


Figure 2: ZigBee Stack Architecture[15]

As shown in figure 2, the IEEE 802.15.4 develops the medium access control (MAC) layer and physical (PHY) layer, which address such things as the frequency and data rate specifications. The physical layer allows for two types of devices: full function devices (FFDs) and reduced function devices (RFDs). FFDs can function in any topology, are capable of being a coordinator or the Network coordinator and it can talk to any other device. RFDs are limited to star topology. It cannot be a network coordinator, yet very simple implementation.

ZigBee develops the network layer and application layer including the applications support sublayer, the ZigBee device object, and the security services. The network layer and application layer are more specific than the IEEE layers and involve such things as how a ZigBee network is to be set up, how the devices in the network relate to one another, and so on.

Among other things, the NWK or network layer is the layer where networks are started, joined, left and discovered, it ensures the proper operation of the underlying MAC layer and provides an interface to the application layer. The network layer supports star, tree and mesh topologies which will be described in the figure 3 below:

## Star Topology

A Star network has a central node, which is linked to all other nodes in the network. All messages travel via the central node. the communication is established between devices and a single central controller, called the PAN coordinator. The PAN coordinator may be mains powered while the devices will be battery powered.  After the first time, an FFD is activated, it may establish its own network and become the PAN coordinator. Each start network chooses a PAN identifier, which is not currently used by any other network within the radio sphere of influence. This allows each star network to operate independently. However, it is unnecessary to use ZigBee network layer to implement a star network since a star topology is provided by the IEEE802.15.4 layer such in cases when :
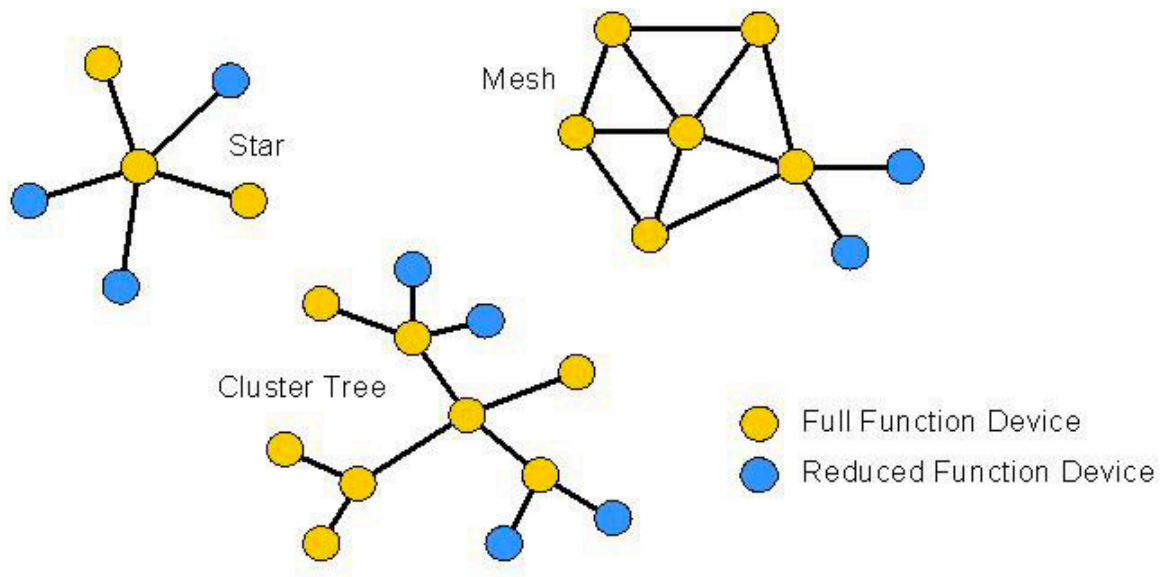


Figure 3 : Network Topologies[14]

I) The ZigBee network layer is not in use, the coordinator will relay messages.
II) The ZigBee network layer is in use, the coordinator will pass messages to their destinations transparently to the application program.

The advantage of star topology is that applications for home automation, personal computer (PC) peripherals, toys and games benefit from this topology, but the disadvantage is that there is no alternative route if the RF link fails between the Co-ordinator and the target device. In addition, the Co-ordinator can be a bottleneck and cause congestion.

## Cluster-Tree Topology

A Tree network is a special case of a mesh network in which most devices are FFDs and an RFD may connect to a tree network as a leave node at the end of a branch. Any of the FFD can act as a coordinator and provide synchronization services to other devices and coordinators but only one of these coordinators is the PAN coordinator.

The PAN coordinator forms the first cluster by establishing itself as the cluster head (CLH) with a cluster identifier (CID) of zero, choosing an unused PAN identifier, and broadcasting beacon frames to neighboring devices. A candidate device receiving a beacon frame may request to join the network at the CLH. If the PAN coordinator permits the device to join, it will add this new device as a child device in its neighbor list. The newly joined device will add the CLH as its parent in its neighbor list and begin transmitting periodic beacons such that other candidate devices may then join the network at that device. Once application or network requirements are met, the PAN coordinator may instruct a device to become the CLH of a new cluster adjacent to the first one.

The advantage of this clustered structure is the increased coverage area at the cost of increased message latency, even though the disadvantage is that there is no alternative route if a necessary link fails.

## Mesh Topology

The structure of the mesh topology is similar to that of the cluster-tree topology, with the coordinator at the top of a tree-like structure, there is one PAN coordinator. Any device can communicate with any other device as long as they are in range of one another. A mesh network can be ad hoc, self-organizing and self-healing. The communication rules are more flexible in Router nodes within range of each other can communicate directly.

The advantage from this topology is the applications such as industrial control and monitoring, wireless sensory networks, asset and inventory tracking would gain benefits from such a topology. It also allows multiple hops to route messages from any device to any other device in the network. It can provide reliability by multi-path routing. However, the disadvantage is this topology gives rise to more efficient message propagation, and means that alternative routes can be found if a link fails or there is congestion.

Comparison of ZigBee Devices on the Network Layer[17]:

| ZigBee Network Layer Function | Coordinator | Router | End Device |
|---|:---:|:---:|:---:|
| Establish a ZigBee network | • | | |
| Permit other devices to join or leave the network | • | • | |
| Assign 16-bit network addresses | • | • | |
| Discover and record paths for efficient message delivery | • | • | |
| Discover and record list of one-hop neighbors | • | • | |
| Route network packets | • | • | |
| Receive or send network packets | • | • | • |
| Join or leave the network | • | • | • |
| Enter sleep mode | | | • |

When a coordinator attempts to establish a ZigBee network, it does an energy scan to find the best reduced-function channel for its new network. When a channel has been chosen, the coordinator assigns the logical network identifier, also known as the PAN ID, which will be applied to all devices that join the network. A node can join the network either directly or through association. To join the network directly, the system designer must add a node's extended address into the neighbour table of a device. The direct joining device will issue an orphan scan, and the node with the matching extended address (in its neighbor table) will respond to allow the device to join. To join by association, a node will send out a request on a channel, repeating the request on other channels until it finds an acceptable network to join. The network layer provides security for the network, ensuring both authenticity and confidentiality of a transmission.

According to figure 2, the Application Support Sublayer or APS layer is responsible for binding tables, message forwarding between bound devices, group address definition and management, address mapping from 64-bit extended addresses to 16-bit NWK addresses, fragmentation and reassembly of packets  and reliable data transport.

The key to interfacing devices at the need or service level is the concept of binding. Binding tables are kept by the coordinator and all routers in the network. The binding table maps a source address and source endpoint to one or more destination addresses and endpoints. The cluster ID for a bound set of devices will be the same.

ZigBee Device Object (ZDO) is responsible for overall device management, specifically it is responsible for initializing the APS sublayer and the NWK layer, defining the operating mode of the device (i.e., coordinator, router, or end        device), device discovery and determination of which application services the device provides, initiating and/or responding to binding requests and security management

Device discovery can be initiated by any ZigBee device. In response to a device discovery inquiry end devices send their own IEEE or NWK address (depending on the request). A coordinator or router will send their own IEEE or NWK address plus all of the NWK addresses of the devices associated with it. (A device is associated with a coordinator or router if it is a child node of the coordinator or router.) Device discovery allows for an ad-hoc network. It also allows for a self-healing network. Service discovery is a process of finding out what application services are available on each node. This information is then used in binding tables to cohere a device offering a service with a device that needs that service.

## Data Transmission

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 used in most of the countries worldwide. The 868 MHz band is specified primarily in Europe, 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 regulations of the Federal Communications Commission (FCC).

In this standard, the 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 stated, but due to the overhead of the protocol the actual theoretical maximum data rate is approximately in 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 particularizes 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. The graph in figure 4 below shows the various channels at the spacing specified by 802.15.4.
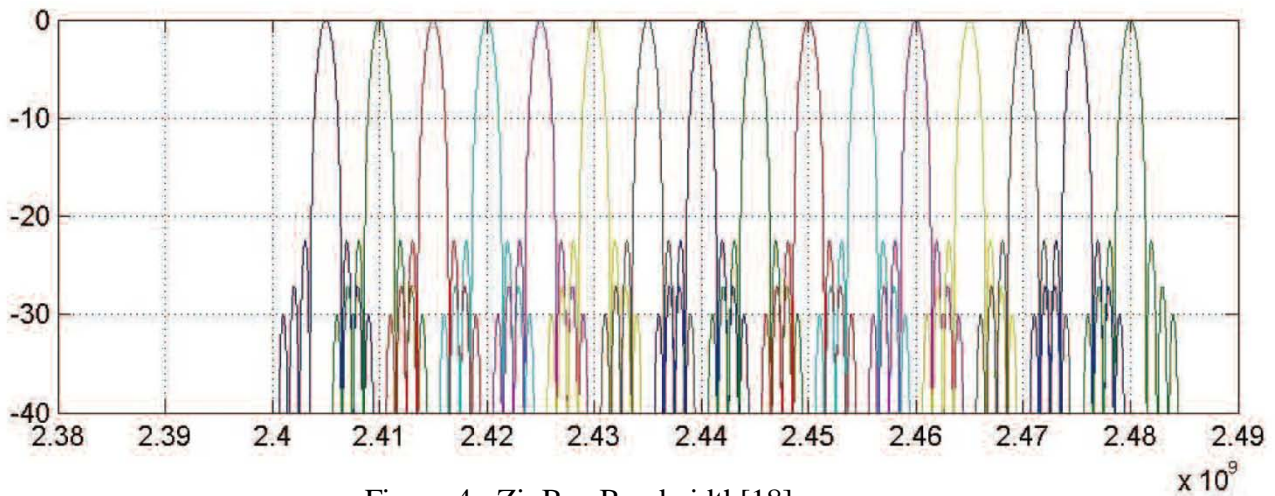
Figure 4 : ZigBee Bandwidth[18]

## Transmission Media

ZigBee are expected to transmit 10-75 meters, depending on the RF environment and the power output consumption required for a given application.    The antenna that is used for ZigBee, is omni-directional antenna.

## Signal Encoding Technique

The IEEE802.15.4 specifies 4 PHY layers which are :

I.)   An 868/915 MHz direct sequence spread spectrum (DSSS) PHY : employs binary phase-shift keying(BPSK) modulation.

II.) An 868/915 MHz DSSS PHY : employs offset quadrature phase-shift keying (O-QPSK) modulation (optional)

iii.) An 868/915 MHz parallel sequence spread spectrum (PSSS) PHY: employs BPSK and amplitude shift keying (ASK) modulation (optional)

IV.) A 2450 MHz DSSS PHY : employs O-QPSK modulation.

The 868/915 MHz DSSS that uses binary phase-shift keying (BPSK) modulation and the 2450 MHz DSSS using O-QPSK modulation are supported in the ZigBee Design Library

The contents in the table below show information of modulations which describe how the signals are encoded in different PHY layers [2] :

# Errors

ZigBee uses error detection and repeat transmissions(retransmissions) for reliable communicating, however ZigBee does not have error correction process. The MAC layer uses two strategies of the automatic retransmission request(ARQ) and the frame buffer. The sender should receive the confirmation before sending the next frame to ensure the communications are trusty.

# Application

ZigBee applications are created for various goals based on commercial demands which are of 5 main purposes[5] :

1.) Home Entertainment and Control - Smart lighting, advanced temperature control, safety and security, movies and music

2.) Home Awareness - Water sensors, power sensors, energy monitoring, smoke and fire detectors, smart appliances and access sensors

3.) Mobile Services - m-payment, m-monitoring and control, m-security and access control, m-healthcare and tele-assist

4.) Commercial Building - Energy monitoring, HVAC, lighting, access control

5.) Industrial Plant - Process control, asset management, environmental management, energy management, industrial device control, machine-to-machine (M2M) communication

# Usage

ZigBee Alliance has over 100 worldwide membership companies. In Thailand there are some researches on ZigBee launched by NSTDA. However, ZigBee is not extensively used in Thailand since it is somewhat new technology. In addition, there are some added costs for establishing the system.

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# Comparison between each technology

## Protocol

The main concern on protocol for WiMAX and WLAN is to transfer files between two nodes. The main concern on protocol for ZigBee and Bluetooth is to connect to devices. WiMAX has higher security protocol than WLAN since WiMAX learn from WLAN security mistakes. Bluetooth is used to transfer data or audio while ZigBee usually transfer small size of data to and from sensory devices.

## Data Transmission

The bandwidth for WLAN is the highest while WiMAX is second, followed by Bluetooth, and finally ZigBee. WiMAX has the highest frequency range due to how it broadcast its signal. WLAN, Bluetooth and ZigBee has a small frequency range.

## Transmission Media

All of the technology has omnidirectional antenna since there is no need for direction except for WiMAX which has a point to point antenna to transfer data over a long distance. WiMAX also has sector antenna which broadcast its signal in a certain direction.

## Signal Encoding

WLAN and WiMAX has similar signal encoding techniques. Bluetooth encodes it data by using frequency. ZigBee uses phase shift keying to encodes its data.

## Error

Each technology uses FEC for error detection and error correction except for ZigBee. ZigBee does not have an error correction system. Rather than trying to correct it, Zigbee request a retransfer of data from the source.

## Application

WLAN, Bluetooth, and ZigBee have short transmission range and therefore needs its device to be near the base station. WiMAX on the other hand has a large coverage area for mobility purposes. Devices can connect to WiMAX network anywhere if they are in the coverage area.

## Usage

Every technology is used to transmit data and received data. WiLAN and WiMAX is used to receive any kind of data. Bluetooth is customized for fast audio transmission and receive. ZigBee is used to detect anything from its sensor that is connecting to the network.

## Cost

Each technology is purchasable except for WiMAX. WiMAX has expensive equipments and construction cost which makes it unpopular to users who which to transfer from WLAN to WiMAX causing WiMAX to be a dying technology. WiMAX equipments need to be cheaper in order to attract users to change to WiMAX.