ITS323

Introduction to Data Communications

Assignment 1

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Bluetooth

Bluetooth is a wireless technology using short wavelength radio transmissions to exchange data over short distances. It was named after the Danish King Harald Bluetooth, who united two warring countries, as for the idea of uniting two devices to remotely work together. Bluetooth was first developed by Ericsson Mobile Communications in 1994, with the initial aim of replacing cable technology. It is considered to be a low cost, low power interface which creates personal area networks (PANS) with high security levels.

Protocol Architectures

Bluetooth communication communicates between a master radio and a slave radio that are symmetric, meaning that a master radio can operate as either master radio or slave radio, and vice versa. Radio devices form networks called piconets which share the same channel. The master can communicate up to 7 slaves in a piconet.

Layered Stacks

Bluetooth can be divided into 4 main Layers as followed:

L2CAP
LMP
LC
Radio

1. Radio Layer (RF)

    In this layer, packets are transmitted and received on the physical channel. The timing and frequency carrier is controlled by a baseband.

2. Link Controller Layer (LC)

    The packets from physical channel, logical transport and logical link are encoded and decoded in this layer.

3. Link Manager Protocol Layer (LMP)

    Logical links are created, modified, and released in this layer.

4. Logical Link Control and Adaptation Protocol Layer (L2CAP)

    The submission of PDU fragments to the baseband is managed and ordered by the L2CAP resource manager in this layer.

Protocols

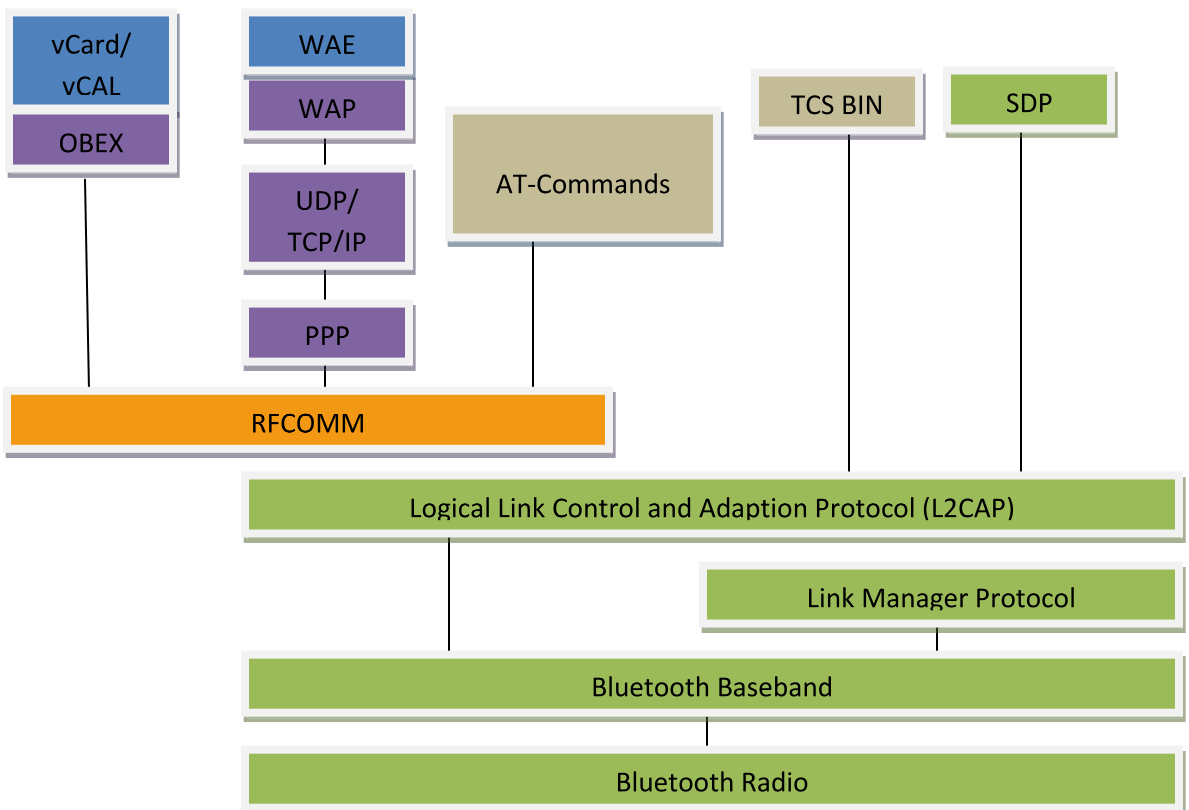


Figure 1: Bluetooth Protocol Stack

The protocols of the Bluetooth stack can be divided into four different categories: core protocols, cable replacement protocols, telephony control protocols, and adopted protocols.

1. **Bluetooth Core Protocols**
    a. Baseband

    The baseband and the link control layers enable the Bluetooth device to form a piconet via radio frequency link.

    b. Link Manager Protocol (LMP)

    The link manager protocol is used to control the radio link.

    c. Logical Link Control and Adaptation Protocol (L2CAP)

    The logical link control and adaptation protocol is used in order to multiplex the logical address between devices.

    d. Service Discovery Protocol (SDP)

    The service discovery protocol allows devices to search for available services supported by other devices.

2. **Cable Replacement Protocols**
    a. Radio Frequency Communications (RFCOMM)

    The RFCOMM protocol is the cable replacement protocol which provides a reliable serial data stream. It is considered as a transport protocol.

3. **Telephony Control Protocols**
    a. Telephony Control – Binary (TCB)
    The TCB controls the signal when speech and data between devices established.
    b. Telephony Control – AT Commands

    A set of AT Commands are defined in order to control the usages of mobile phone and modem.

4. **Adopted Protocols**
    The adopted protocols are protocols in Bluetooth that created by other standard. It is used for controlling the Bluetooth to create protocols only when needed. Adopted Protocols include:
    a. Point-to-Point Protocol (PPP)

    The PPP protocol allows devices to transport IP datagram via a point-to-point connection.

b. TCP/UDP/IP

TCP/UDP/IP is used for all Internet usage.

c. Object Exchange Protocol (OBEX)

OBEX is used when exchanging object between devices.

d. Wireless Application Protocol (WAP)

WAP is used to create a framework for wireless device application.

Standards

Bluetooth v1.1 and its updated version Bluetooth v1.2 were defined by IEEE 802.15.1 standard. However, the IEEE (Institute of Electrical and Electronics Engineers) has discontinued deriving the standard for latter version of Bluetooth.

Standard Organizations

The Institute of Electrical and Electronics Engineers once developed the standards for Bluetooth. Nowadays, however, the specifications of Bluetooth were formalized by the Bluetooth Special Interest Group (SIG).

Data Transmission

Spectrum

Bluetooth operates using frequency-hopping spread spectrum technology which transmits data via short range low power radio waves in the 2.4 GHz spectrum.

Frequency

Bluetooth communicates on a frequency between 2.402 GHz and 2.480 GHz (2.45 gigahertz), which is not licensed by international agreement for the use of industrial, scientific and medical devices (ISM).

Bandwidth

Bluetooth technology is well performed in a data transmission that requires low bandwidth, and the devices are not very far from each other. Bluetooth data channel has a capacity of 1 megabit per second (Mps), with the frequency range of 2.4 GHz.

Data rates

Bluetooth technology has developed new version of devices to improve the data rate of devices for the faster transfer.

Bluetooth Low Energy Technology:	1 Mbit/s
Version 1.2:	1 Mbit/s
Version 2.0 EDR:	1 Mbit/s upto 3 Mbit/s
Version 3.0 HS:	up to 24 Mbit/s

Transmission Media

Bluetooth devices are designed to have low power consumption, allowing radios to power down when inactive.

Transmit power

Bluetooth devices can be categorized into three different power classes. The maximum output from a Bluetooth radio is 100 mW (20 dBm) for Class 1, 2.5 mW (4 dBm) for Class 2, and 1 mW (0 dBm) for Class 3. Tough Class 1 has the highest power consumption; it is best used in the applications that require the greater range. Most of the Bluetooth devices are found in Class 2.

Receive Thresholds

The receiver sensitivity of any Bluetooth transmitter must be below or equal to -70 dBm.

Antennas

The Bluetooth radios range can be extended up to a mile with directional antennas and signal amplifiers. To create Bluetooth antenna, a structure that is resonant at 2.45 GHz with the bandwidth greater than 100 MHz and efficiency >50% need to be created. Examples of common types of Bluetooth antenna are Wire Monopole, Printed Inverted F Antenna (PIFA), Helix, and Ceramic.

Distance

The Bluetooth can operate over a minimum distance of 1 meter, 10 meters, or 100 meters depending on which power-class it is in. But in practice, the distance is varied depending on the microchip used in the devices.

Class	**Maximum Permitted Power**		**Range (approximate)**
	mW	**dBm**	
Class 1	100	20	~100 meters
Class 2	2.5	4	~10 meters
Class 3	1	0	~1 meters

Table 1: Bluetooth Power Class and Range

Signal Encoding Techniques

In Classical Bluetooth, the Gaussian Frequency-Shift Keying (GFSK) is used for modulation. The data can be transmitted at a rate of 1 Mbit/s.

After Bluetooth v2.0 + EDR were developed in 2004, the modulation of Bluetooth was changed. This new version of Bluetooth technology combined the modulation of GFSK, the former modulation used in previous version, and Phase Shift Keying modulation (PSK) together. The data rate was increased to 3 Mbit/s and lower power consumption was provided.

The modulation schemes were added for EDR when the Bluetooth v3.0 + HS were developed. It increased modulation index which then provides a possible range for Bluetooth low energy technology of over 100 meters. In this version, the data transfer rate is increased up to 24 Mbit/s.

Errors

In electromagnetically noisy environments, there exists high chance for the Bluetooth of being interfered. Therefore, error-detection and error-correction is needed.

For the error detection, various Checksum-Calculations are used to detect errors occurred in data transmission via Bluetooth devices.

For the error correction, three types of error correction schemes are implemented in Bluetooth technology.

1. 1/3 Rate Forward Error Correction (FEC)
2. 2/3 Rate Forward Error Correction (FEC)
3. Automatic Repeat-Request (ARQ)

The FEC scheme aims to reduce the number of retransmissions. However, FEC reduces the throughput due to its unnecessary overhead in the error-free environment.

In the ARQ scheme, the data packets will be retransmitted until an acknowledgement is received or timeout is exceeded.

Applications

Bluetooth is intended to be in applications which require low bandwidth and low power consumption, mostly voice and data applications. The security level is also one of the highest priorities of Bluetooth. The Bluetooth devices are mainly work as cable replacement and create connectivity between PDA's, laptops, mobile phones, and other such devices. Compared to other technology, such as ZigBee, Bluetooth relies on frequent battery charging.

Nowadays, Bluetooth technology is used in various fields; for example,

- Wireless Communication between PCs and mobile phones
- Wireless Communication between PC input and output devices: mouse
- Serial Communication: bar code scanner, medical devices
- Replace the Infrared technology
- Game Console: Nintendo's Wii, Sony's PlayStation3
- Dial-up internet access: PDAs

Usage

Bluetooth is the popular technology used by people all over the world, including Thailand. Anyway, since it can transmit data that requires low bandwidth over short distances, the number of Bluetooth users is a lot lower than other broadband wireless technology like WiMAX.

Cost

Approximated Cost of Equipment

Bluetooth is a low power consumption technology that uses low cost transceiver microchips which manufacturing cost is around $3-$5 for its devices.

Other Costs Associated with Using the Technology

There is no charge for communication between Bluetooth devices since Bluetooth Technology operates on an unlicensed radio spectrum.

ZigBee

ZigBee is a wireless technology developed by ZigBee Alliance. Its name is originated with reference to the behavior of honey bees when they harvest pollens which are similar to the way the packets are moved through a mesh network. It is the low data rate Wireless Personal Area Networks (WPANs) which are basically used to convey the information in the short distance. The aim of developing ZigBee is to overcome the limitations of Bluetooth and Wireless LAN (Wi-Fi). ZigBee is designed to provide highly efficient connectivity between small packet devices, whereas Bluetooth focuses on connectivity between large packet user devices. ZigBee is good in term of its low cost and low power consumption. ZigBee was developed to provide the users with ultimate flexibility, mobility, and ease of use.

Protocol Architecture

The IEEE (Institute of Electrical and Electronics Engineers) developed the IEEE 802.15 working group to maintain the WPAN standard. ZigBee is a LR-WPAN (Low Rate Wireless Personal Area Networks) based on IEEE 802.15.4. IEEE 802.15.4 defines a communication at two layers which are Medium Access Control (MAC) protocol, one of the two sub-layers of Data Link layer, and Physical protocol.

ZigBee takes full advantage of the IEEE 802.15.4 standard with and adding four more main components: network layer, application layer, ZigBee device objects (ZDO's), and manufactured-defined application objects. IEEE and ZigBee Alliance have been working together to specify the entire protocol stack. IEEE 802.15.4 works on the specification of the lower two layers of the protocol (Physical and Datalink layer). On the other hand, ZigBee Alliance works on the specification of the upper layers of the protocol stack (from network to the application layer).

Apart from adding two more layers, the more significant improvement in ZigBee is the ZDO's which are responsible for many tasks. For example, management of requests to join a network, keeping of device roles, and device discovery and security

Unlike Bluetooth, ZigBee devices have the ability to form a mesh network between nodes. Meshing allow the directly connect from one device to another. It provides high reliability and more extensive range.

Physical Layer

The PHY layer provides two services which are the PHY data service and the PHY management service.

The PHY data service provides the transmission and reception of PHY protocol data units (PPDUs) across the physical radio channel.

The PHY management service provides activation and deactivation of the radio transceiver, energy detection(ED) with the current channel, link quality indication (LQI) for received packets, channel frequency selection, clear channel assessment (CCA) for CSMA-CA and data transmission and reception of packets across the physical medium.

The PHY layers for 2.4 GHz and 868 MHz/915 MHz frequency band are different. The differences can be illustrated by the following tables:

PHY layer of 2.4 GHz frequency band

Channel	Frequency (MHz)	Spectrum	Modulation
11-26	2400.00-2483.5	Between each channel, there is a spectrum of 5 MHz.	Offset-Quadrature Phase Shift Keying (OQPSK)

PHY layer of 868 MHz/915 MHz frequency band

Channel	Frequency (MHz)	Spectrum	Modulation
0	868.0-868.6	Between each channel, there is a spectrum of 2 MHz.	Binary Phase Shift Keying (BPSK)
1-10	902-928		

Table 2: PHY Layer Specification

Data Link Layer

The MAC sublayer provides two services which are the MAC data service and the MAC management service.

The IEEE 802.15.4 MAC defines four frame structures as follow:

- A beacon frame: used by a coordinator to transmit beacons
- A data frame: used for all data transfers
- An acknowledgement frame: use for confirming successful frame reception
- A MAC command frame: use for handling all MAC peer entity controls

The features of MAC sublayer are beacon management, channel access, a guaranteed time slot (GTS) mechanism, frame validation, acknowledged frame delivery, and association and disassociation.

The comparison between OSI layered model and the ZigBee model can be illustrated by the following diagram:

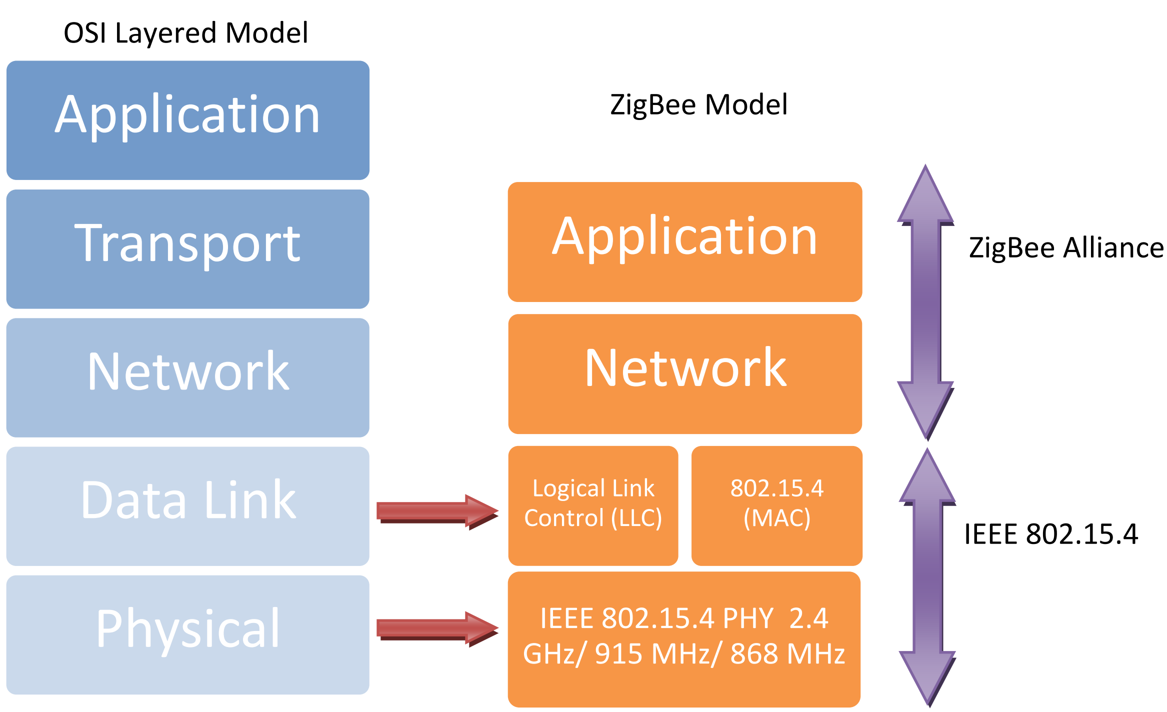


Figure 2: OSI Layered Model and ZigBee Model

Data Transmission

ZigBee operates on three different license free frequency bands, the 2.4 GHz which is available throughout most of the world, the 915 MHz which is used in the USA and Australia, and the868 MHz which is used in Europe. The maximum data rates for each band are 250 kbps, 40 kbps and 20 kbps, respectively.

The number of channels allotted to each frequency band is fixed at 16 channels in the 2.4 GHz band, 10 channels in the 915 MHz band, and 1 channel in 686 MHz band.

ZigBee's average power consumption is very low as it can sleep most of the time. It is very responsive, only 15 msec or less is needed for ZigBee to activate.

Transmission Media

ZigBee was designed to support the range between 10 to 100 meters. But in the case of special kit or outdoor, it can provide up to 400 m. It can penetrate one concrete wall, but not two. ZigBee can support 2 to 65000 devices per network. The maximum output power of the radios is generally 0 dBm (1 mW).

The 802.15.4 standard specifies a minimum receiver sensitivity of -85 dBm for 2.4 GHz radio and -92 dBm for 900MHz radio.

Signal Encoding Technique

ZigBee uses DSSS (Direct Sequence Spread Spectrum) to modulate the information before sent to the physical layer. The Offset-Quadrature Phase Shift Keying (OQPSK) is used for 2.4 GHz and the Binary Phase Shift Keying (BPSK) is used for 868 MHz and 915 MHz.

Errors

ZigBee uses Cyclic Redundancy Check (CRC) to detect errors. When errors are detected, ZigBee use re-transmissions, unlike Bluetooth that use Forward Error Correction.

Applications

ZigBee is intended to be used in embedded applications which require low data rates and low power consumption. ZigBee is expected to provide low power connectivity for equipment that needs battery life as long as several months or even to several years. So, ZigBee is suitable for install-and-forget purposes, such as small household systems. But ZigBee is not suitable if the users require the high data rates. ZigBee is easy to install.

Nowadays, ZigBee is being used in many areas, for example;

- Medical: medical data collection
- Home Automation: water sensors, power sensors, smoke and fire detectors, smart lighting, temperature controls, intruder warning, wireless door and opening monitoring, wireless keypads
- Home Entertainment: home entertainment systems
- Video Conference Equipment: Remote Control
- Video Gaming Equipment: multiplayer PC and video games, interactive toys
- Mobile Service
- Commercial Automation: access control, energy monitoring
- Industrial Automation: process control, asset management, environmental management, tracking wind turbines
- Private Security
- Consumer Products: cellular handsets
- Military and government systems: asset tracking

Furthermore, nowadays, there is a ZigBee Heath Care which provides a global standard for use in homes, fitness centers, and etc. It enables secure and reliable monitoring and management of noncritical, low-acuity healthcare services targeted at chronic disease. ZigBee Health Care will help people live healthier, happier independent lives. It can lowers healthcare costs as the transportation is not needed.

Usage

ZigBee is used by people around world. As it operates on the 2.4 GHz frequency band which is the unregulated frequency, it is allowed in most of the country worldwide, including Thailand.

Cost

Pricing of ZigBee comparing with other technologies is considered to be low. Based on the information from 2003, the module cost is $1.5-$2.5. ZigBee costs only half of the Bluetooth.

For most application, the battery life can last for years. So, the cost for the batteries is not necessary to be worried about.

Wireless LAN

The Wireless Local Area Network (WLAN) is a Local Area Network (LAN) which doesn't depend on the wired Ethernet connections. To transmit data, radio transmission is used instead of cables. WLAN connect end user deices over a local coverage area. Nowadays, WLAN is widely used in house, shopping mall, coffee shops, and etc. WLAN have become more and more popular as it is easy to install. Most commonly, a WLAN access point provides access within a radius of 65 to 300 feet.

WLAN provides users more flexibility of movement as it enables one or more devices to communicate without physical connections. WLAN is suitable for the area where there is inconvenient or impossible to lay cables. It can be used to create a temporary network for a specific amount of time.

Protocol Architecture

IEEE (Institute of Electrical and Electronics Engineers) organization developed IEEE 802.11 series which is the set of standards that defines WLAN. Like all IEEE 802 standards, the 802.11 standards defines the only on the bottom two layers of the OSI layered model. IEEE 802.11 defines the Medium Access Control (MAC) protocol, one of the two sub-layers of Data Link layer, and Physical protocol.

Physical Layer

Three different physical layers are defined in the 802.11.

- A radio physical layer using FHSS technique operating in the 2.4 GHz frequency band
- A radio physical layer using DSSS technique operating in the 2.4 GHz frequency band
- A physical layer for the IR transmission

The physical layer is structured is two sublayers which are a Physical Layer Convergence Procedure (PLCP) sublayer and a Physical Media Dependent (PMD) sublayer.

PLCP has an interface for the MAC sublayer to write to and provides carrier sense and Clear Channel Assessment (CCA). The purpose of this layer is to take care of the lower sublayer.

PMD defines the method of transmitting and receiving data through a wireless medium between two or more stations that use the same modulation schemes. It has a responsible for the wireless encoding.

Data Link Layer

The data link layer is subdivided in two sublayers which are Logic Link Control (LLC) and Media Access Control (MAC). The LLC sublayer is same as other 802 LANs of the IEEE, but MAC is different. IEEE 802.11 defines new mechanisms of access to the medium. The IEEE 802.11 family uses a MAC layer known as Carrier Sense Multiple Access with Collision Avoidance CSMA/CA as the medium access method.

The services that are supported by this layer are:

- Asynchronous data transmission service
- Time constraints traffic service
- Association/disassociation
- Authentication and access control

802.11 layers can be compared with the OSI layered model by the following figure:

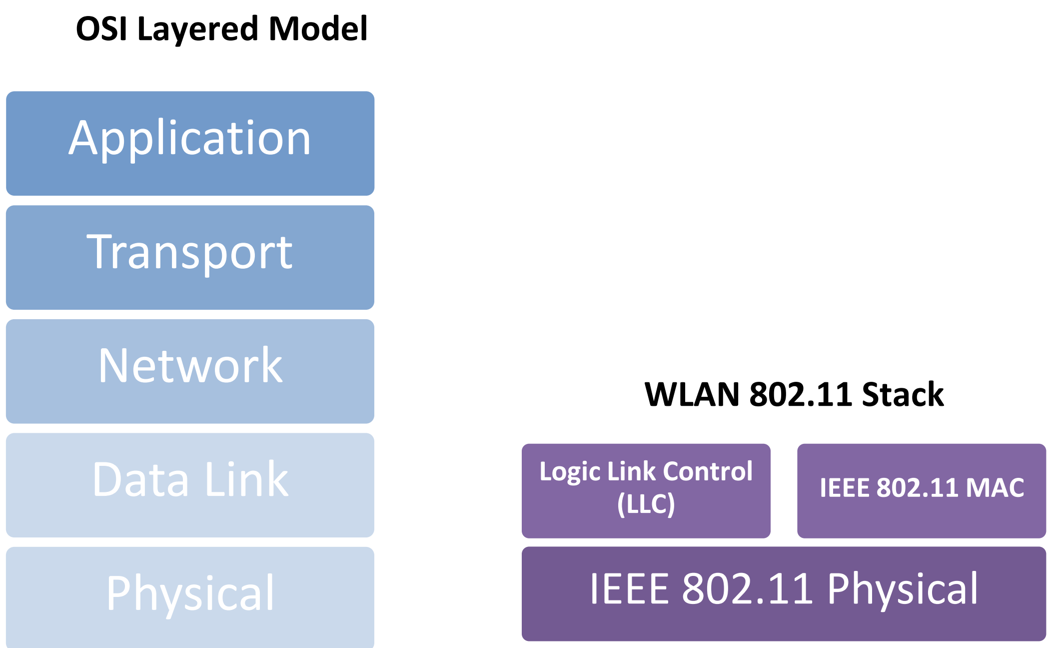


Figure1: Internet Stack and IEEE 802.11 Stack

Data Transmission and Signal Encoding Techniques

The IEEE 802.11 family consists of 802.11, 802.11a, 802.11b, 802.11g, 802.11n, and etc. Some standards are now developing and not yet finalized. The letters after the number 802.11 tell us the order in which the standards were proposed. Different standards have different data rate, bandwidth, frequency, spectrum, range and encoding schemes. Each of them has their own pros and cons. The brief details of each standard are as follow:

IEEE 802.11

IEEE 802.11 was the first WLAN standard. It was the first version of IEEE 802.11 which is released in June 1997. It provides data transfer rates up to 2 Mbps which is too slow for most applications. The bandwidth of 802.11 is 20 MHz. It operates on the 2.4 GHz frequency band.

The approximate indoor range is 20 m. The approximate outdoor range is 100 m. It specified three physical layer technologies which are diffuse infrared, frequency-hopping spread spectrum, and direct sequence spread spectrum. The other 802.11 standards are developed based on the amendment of this 802.11 standard. Nowadays, 802.11 is no longer manufactured.

802.11 uses either Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS) as a carrier to transmit data. While it uses either Frequency Shift Keying (FSK) or Phase Shift Keying (PSK) for actual signal modulation. So, the digital data will be modulated into analog signal before sending.

The advantage of 802.11 is that it is the first Wireless local area networking which provide freely movement for the user while connecting to the network.

The disadvantage of 802.11 is that it has very slow data rate, expensive, and has poor security.

IEEE 802.11a

Released in September 1999, IEEE 802.11a provides data transfer rates up to 54Mbps. High data rate is not the only advantage of 802.11. It also operates in 5GHz frequency band which is a less crowded, wider, and more regulated frequency than the 2.4 GHz band. So, it is less interfered by other devices. Its bandwidth is 20 MHz. It allows eight simultaneous channels.

Because it operates in the higher frequency, 802.11a has a shorter range and is limited more by physical barriers. The approximate indoor range is 35m. The approximate outdoor range is 120m.

An Orthogonal Frequency Division Multiplexing (OFDM) is used to transmit data. Signals are broken down into 52 sub-carriers (48 data and 4 pilots) that are then transmitted at different frequencies to the receiver simultaneously. Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM) is used for the actual signal modulation. It means that the digital data will be modulated into analog signal before sending. As data rate increases, the modulation becomes more complex and more fragile.

The advantages of 802.11a are its fast maximum speed and its prevention from signal interference from other devices as it operates on the more regulated frequency. So, 802.11a is suitable to be used in the areas with significant interference, such as airports, and business call centers. It is also considered to be better at maintaining connections. Moreover, the spectrum of 802.11a is divided into eight channels. These channels are responsible for a number of network nodes. The channels are made up of 52 carriers and it can present a maximum of 54 Mpbs.

The disadvantages of 802.11a are that it is less able to penetrate physical barriers, expensive, and providing short range. While 802.11a and 802.11b share the same MAC layer technology, there are significant differences at physical layer. So, 802.11a is completely incompatible with 802.11b. The new bridging products are required to support both types of networks. So, an extra cost is added.

Moreover, 5GHz band is the more regulated frequency, which is not allowed to be used in Thailand and many other countries. 802.11a is now approved by regulations in the United States and Japan, but in European Nations, it still had to wait for the approval.

On 2008, the extension of 802.11, IEEE 802.11y-2008 was developed. It extended operation to the licensed 3.7 GHz band. The range allowed then become 5000 m.

IEEE 802.11b

On September 1999, IEEE 802.11b which is also known as Wi-Fi was released. It was released at the same time with 802.11a. But it gained popular much faster. It could be said that 802.11b is the most widely accept standard among 802.11 standard series. With 802.11b WLAN, users can get Ethernet levels of performance and throughput.

Since IEEE 802.11b is a direct extension of IEEE 802.11, it uses the same media access method which is used in the 802.11 standard. 802.11b is the enhancements of the 802.11 to support 5.5 and 11 Mbps data rates. It provides data transfer rates up to 11Mbps and operates on the 2.4 GHz frequency band. 802.11b provides wider range than 802.11a. The physical layer of 802.11b provides higher data rate and more robust connectivity. The approximate indoor range is 38m. The approximate outdoor range is 140m. 802.11b is used in a point-to-multipoint configuration.

In IEEE 802.11b, the DSSS is used as a carrier to transmit data. It has one carrier per channel. The Complementary Code Keying (CCK) is used for the actual signal modulation. It means that the digital data will be modulated into analog signal before sending. The CCK allows higher data speeds and is less susceptible to multipath propagation interference.

The advantage of 802.11b is its lower cost. So, 802.11b usually serves the home market unlike 802.11a which is usually found on the business network. It’s also has a good range and better at penetrating physical barriers.

The disadvantage of 802.11b is that it has the slowest maximum data rates (not included 802.11). Apart from this, as it operates on 2.4 GHz which is the unregulated frequency that is used by many devices, for example microwave ovens, Bluetooth devices, and cordless phones. It is more susceptible to interference. So, it is not good for applications that require absolutely reliable connections, such as live video streaming.

The 802.11b is suitable to use for internet access only as the device can transfer data up to 11Mbps which is sufficient for the internet use as the broadband modem is operating at about 2 Mbps (depending on the area).

IEEE 802.11g

802.11g was released on Jun 2003. It attempts to combine the best properties of both 802.11a and 802.11b. It supports data transfer rates up to 54Mbps on the 2.4 GHz band. Its bandwidth is 20 MHz. The approximate indoor range is 38m. The approximate outdoor range is 140m. 802.11g is backward compatible with 802.11b.

The 802.11g uses OFDM to transmit data. It uses PSK or QAM for the actual signal encoding. In the fallback mode, DSSS is used to transmit data, and CCK is used for the actual signal encoding for data rates of 5.5 and 11 Mbps. It means that the digital data will be modulated into analog signal before sending. Signals are broken down into 52 sub-carriers (48 data and 4 pilots) that are then transmitted at different frequencies to the receiver simultaneously.

The advantage of 802.11g is that it has the fast maximum speed. Furthermore, 802.11g is backward compatible with 802.11b.

The disadvantage of 802.11g is that it costs more than 802.11b. As same as 802.11b, some devices may interfere on the unregulated 2.4 GHz signal frequency. Even though802.11a and 802.11b are compatible without requiring additional devices, while working together; they can operate only at 802.11b, 11 Mbps, speeds.

The IEEE 802.11g is suitable to use for internet access, and file sharing around the home or office.

IEEE 802.11n

On October 2009, the IEEE 802.11n was released. It attempts to improve network throughput over 802.11a and 802.11g by adding Multiple-Input Multiple-Output (MIMO) technology and 40 MHz channels to the Physical layer, and frame aggregation to the MAC layer. Its bandwidth is 40 MHz. It provides data transfer rates up to 600 Mbps. It operates on either 2.4 or 5 GHz frequency band. The approximate indoor range is 70m. The approximate outdoor range is 250m. The OFDM is used in 802.11n.

The advantage of IEEE 802.11n is that it provides very high data rates and very wide range. It provides the MIMO technology which uses multiple antennas to coherently transmit more data than possible using a single antenna. MIMO increases both the throughput and the range of the WLAN. Moreover, 802.11n doubles the channel width from 20MHz in 802.11 to 40 MHz. This allows for a doubling of the PHY data rate.

The disadvantage of IEEE 802.11n is that it becomes more complex with the MIMO technology. MIMO technology requires a separate radio frequency chain and analog-to-digital converter for each MIMO antenna. So, this leads to the higher additional cost when using 802.11n.

The following table shows the comparisons between each standard in the IEEE 802.11 family

Standard	IEEE 802.11	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g	IEEE 802.11n
Maximum Data Rate	2 Mbps	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Bandwidth	20 GHz	20 GHz	20 GHz	20 GHz	40 GHz
Frequency	2.4 GHz	5/3.7 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz
Carrier Type	FHSS, DSSS	OFDM	DSSS	OFDM, DSSS	OFDM,DSSS
Signal Modulation	FSK, PSK	PSK, QAM	CCK	PSK,QAM,CCK	PSK, QAM, CKK
Range (Indoor)	20 m	35 m	38 m	38 m	70 m
Range(Outdoor)	100 m	120/5000 m	140 m	140 m	250 m
Compatibility	No longer available	Incompatible with 802.11b or 802.11g	Widest adoption	Compatible with 802.11b. Incompatible with 802.11a.	Compatible with 802.11a, 802.11b, 802.11g
Cost	No longer available	Relatively more expensive	Inexpensive	Relatively Inexpensive	
Public Access	No longer available	None at this time	The number of public hotspots is growing	Compatible with 802.11b hotspots. So, in the nearly	

			rapidly. This allows wireless connection in many places.	future more and more 802.11b hotspots will convert to 802.11g	
Suitability	No longer available	Suitable to use for internet access	Suitable to use for internet access and file sharing	Suitable to use for crowded 2.4 GHz area	Suitable to use for crowded 2.4 GHz area (can also operate on 5 GHz)
Usage	No longer available	Not widely used due to expense and limited range	Widely used	Gaining in popularity	Still not very popular as it just ratified

Table 3: Comparison between IEEE 802.11, 802.11a, 802.11b, 802.11g, 802.11n

Errors

The error detection that the IEEE 802.11 family uses is the Cyclic Redundancy Check (CRC). The error detection used by the IEEE802.11 is the Forward Error Detection (FEC). Nowadays, in the IEEE 802.11n, the Low-Density Parity-Check (LDPC) codes are also added in order to support the FEC schemes too.

Transmission Media

The typical output power is 100 mW. There are various types of antenna available for the WLAN technology. For example,

- Patch antenna
- Omni antenna
- Sector antenna
- Grid antenna
- Yagi antenna
- Multi-polarized antenna
- Circular-polarized antenna

Applications

WLAN are being widely used in many different applications. The examples are as follow:

- Wireless devices
- Smart phones
- Personal Digital Assistants (PDAs)
- Cordless phones with Wi-Fi Voice over Internet Protocol (VoIP) capabilities
- Video game controllers
- Sensors and cameras for security
- Study group meetings

Usage

WLAN is the popular technology used by people all over the world. Anyway, not all standards are allowed to be used. Different national regulatory boards strongly influence the standard. It bases on the law of each country whether which standard is permitted. For example, in Thailand, only frequency 2.4 GHz is allowed. So, the access point devices that are sold in Thailand have only two standards which are IEEE 802.11b and IEEE 802.11g. 802.11a is now approved by regulations in the United States and Japan, but in European Nations, it still had to wait for the approval.

Cost

WLAN hardware are primarily so expensive that it was only used as an alternative to cabled LAN where cabling was difficult or impossible. As time goes by, prices are decreased. The costs are different among each standard, i.e. 802.11b is cheaper than 802.11a and vice versa. The access point for the WLAN costs from $200 to $1000.

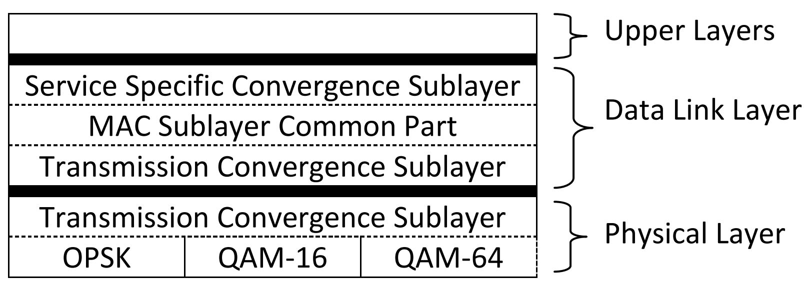
WiMAX

Worldwide Interoperability for Microwave Access or WiMAX provides the technology to broadband Internet access via cell phones as an alternative to cable and DSL. The standard of WiMAX is fall in the category of wireless Metropolitan Area Network (WMAN). Its name came from WiMAX Forum formed in June 2001 in order to promote conformity and interoperability. WiMAX was originally designed to operate at 10-66 GHz and later on was changed in order to operate as a broadband wireless access (BWA) in the 2-11 GHz frequency range. The goal of WiMAX is to provide high-speed Internet access in a range of several kilometers.

Protocol Architectures

IEEE (Institute of Electrical and Electronics Engineers) organization developed IEEE 802.16 series of WiMAX standards. Its current revision is defined in IEEE802.16m.

WiMAX can be divided into three main layers as followed:



1. **Physical Layer**

IEEE 802.16: The original WiMAX has a physical layer that operates in 10 to 66 GHz range.

IEEE 802.16a: The standard of WiMAX was updated in 2004. The specifications for 2 to 11 GHz range were added.

IEEE 802.16e: The standard was updated again in 2005. Orthogonal Frequency-Division Multiple Access (SOFDMA) was used. Multiple antenna were supported through MIMO in this and the latter versions, resulting better terms of coverage, self installation, power consumption, frequency reuse and bandwidth efficiency.

2. **Data Link Layer**

   A scheduling algorithm is used in WiMAX MAC at the first entry of the network. Once it had been subscribed, other subscribers are not allowed to use it.

3. **Upper Layers**

   This layer contains protocols that cannot be mapped into the OSI layer.

Data Transmission

Nowadays, WiMAX has no uniform global licensed spectrum. However, to make WiMAX be more standardized, three spectrum profiles are published by WiMAX Forum: 2.3 GHz, 2.5 GHz and 3.5 GHz.

In operation of WiMAX, two frequency bands are used; 2-11 GHz and 10-66 GHz. The range of WiMAX is about 50 km with the speed of 70 Mbps. WiMAX can either operate at higher bitrates upto 80 Mbps or over longer distances. However, operating WiMAX at the maximum distance causes higher bit error rate and, therefore, reduces the bitrates.

Transmission Media

In order to achieve the long ranges the WiMAX requires, it must have enough transmit power, especially for the long range. The optimal power profile must be kept so that the network has high transmit power and low power consumption.

Power of WiMAX varies with the band. It profiles from 100 Mw up to 2 W. Typically the WiMAX base station transmits at power level of +43 dBm (20W), and at +23 dBm (200mW) for the mobile station. The minimum transmit power is + 23dBm.

The range of WiMAX is about 50 km, which is very long compared to other technologies.

WiMAX is the technology that implemented the Adaptive Antenna System and the Multiple-Antenna technologies called Multiple Input Multiple Output (MIMO). With this implementation, the wireless systems gains the benefits from the multipath phenomenon and therefore create a more robust communication channel.

Signal Encoding Techniques

For the Signal Encoding Techniques of WiMAX, two signal encoding techniques are used as followed:

IEEE 802.16d: OFDM

IEEE 802.16e: SOFDMA

Errors

In order to reduce the Signal to Noise Ratio (SNR), WiMAX has the built-in error detection techniques that are useful for identifying and correcting errors. Convolution Encoding, Strong Reed Solomon Forward Error Correction (FEC), and interleaving algorithms are used to recover the corrupted frames.

Automatic Repeat Request (ARQ) is then used to remove errors that cannot be corrected by the FEC by resending the information of the errors. For the ARQ of WiMAX, Hybrid ARQ scheme is used. The difference of Hybrid ARQ scheme and normal ARQ scheme is that the Hybrid scheme stores the previous transmission data together with the subsequent retransmission data in order to improve reliability. However, the disadvantage of Hybrid ARQ scheme is that the protocol needs to store all the transmission data until the data packets are completely received and the ACK is sent back to the base station, resulting in the requirement of large buffer.

Applications

The bandwidth and range of WiMAX are the main impacts in determining use of applications. The main focus of WiMAX technology is the Metro Area Broadband Internet Connection. It provides both mobile broadband and broadband at home over the countries. Additionally, WiMAX technology is also a good replacement of cellular phone technologies like GSM and CDMA. The examples of this are 2G, 3G, and 4G networks.

Usage

The WiMAX technology is widely used all over the world, in both developed and developing country, including Thailand. The example that we can see is the 3G network.

Cost

It is quite competitive in the markets to access broadband; therefore, it is expensive compared to other technologies like WLAN, Zigbee, and Bluetooth. However, compared to GSM, DSL, or Fiber-Optic, WiMAX network has relatively low cost.

Summary

Some aspects of each technology are able to be compared. The following table shows the differences among each technology.

Technology	Wireless LAN			ZigBee	Bluetooth	WiMax
Standard	802.11a	802.11b	802.11g	802.15.4	802.15.1	**802.16**
Data Rates	54 Mbps	11 Mbps	54 Mbps	< 250 kbps	1 Mbps	**70 Mbps**
Frequency	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz/ 915 MHz/ 868 MHz	2.4 GHz	**3.5/5.8 GHz**
Approximate Range (m)	100	100	100	70-400	< 10	**48000**
Bandwidth	Fixed 20 MHz	Fixed 20 MHz	Fixed 20 MHz		2.4 GHz	**Variable 1-28 MHz**
Interference Risk	Low	High	High		High	**Low**
Application focus	Wireless LAN, Internet			Embedded Applications , Sensor Networks	Data and Voice, Cable Replacement	**Metro Area Broadband Internet Connection**
Power Consumption	High	High	High	Very Low	Moderate	**High**
Cost	Moderate			Very cheap	**Cheap**	**Expensive**
Hotspot Access	**Poor**	**Good**	**Good**	**Poor**	**Poor**	**Good**

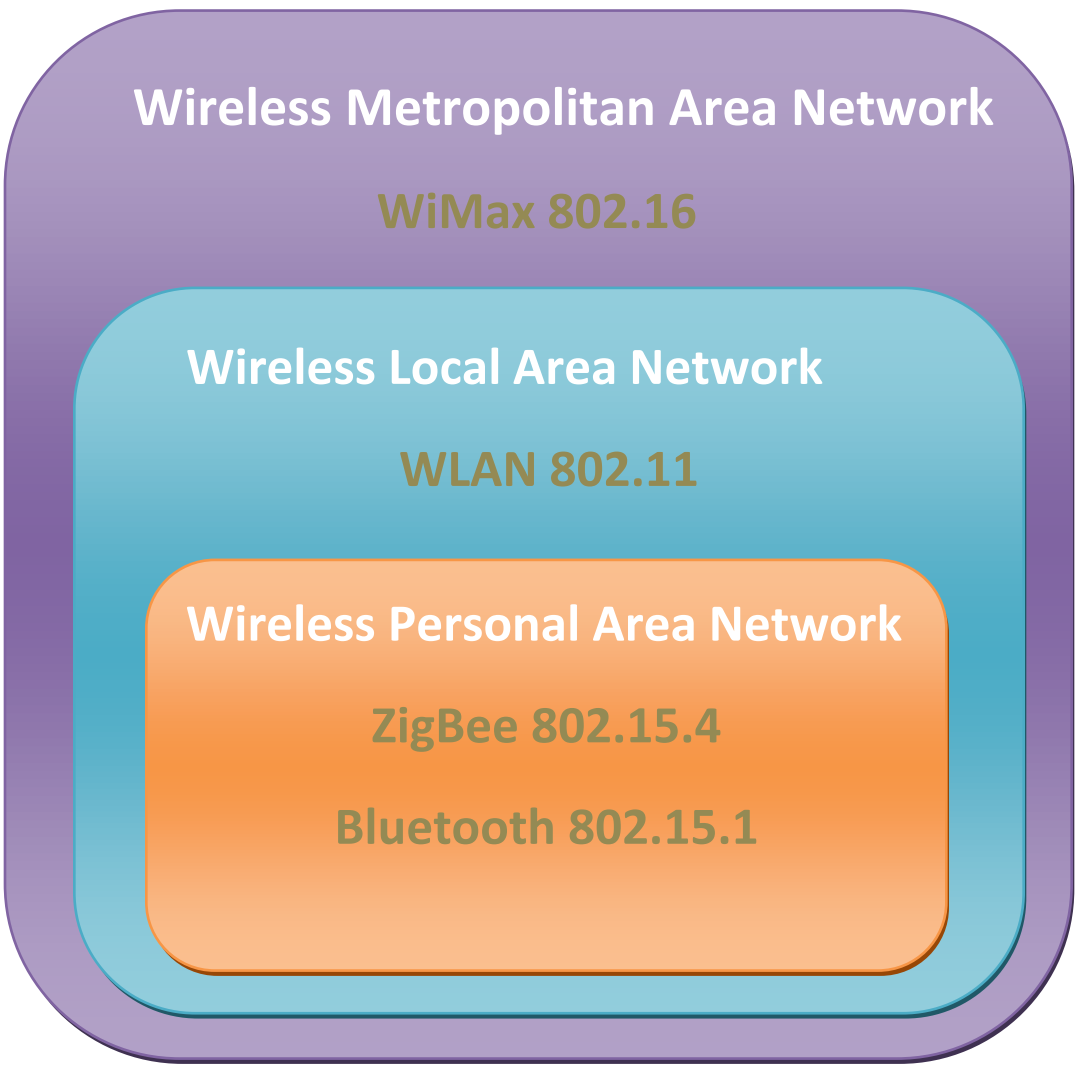
All four technologies stated above: Bluetooth, Wireless LAN, ZigBee, and WiMAX are wireless technology. They provide flexibility for the users in term of movement. Apart from this, it enables the network connections in the area which is difficult to be wired. Each technology has its own pros and cons and is suitable for different purposes.

Bluetooth: Transmit data and voice over short distance in an environment that requires low bandwidth. It provides high level of security for the users.

Wireless LAN: Use of Wireless LAN and Internet without physical connection. It is widely used to provide the network connections in many locations, e.g. coffee shops, airports, department stores, university campuses, and etc.

ZigBee: Focus on embedded applications and sensor networks. It consumes very low power consumption which means the battery can last in very long period of time.

WiMAX: Access Metro Area Broadband Internet Connection covered in both home networks and cellular networks.



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