Wireless Technologies:

ZigBee, Bluetooth, Wireless LAN, and WiMax

Submitted to

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Table of Contents

Members' Participation

Table 1: The percentage of each member participation contributed to each section of the report

Section	Nutchana A.	Kaelkrittaya T.	NichaP.
1			
1.1	10	40	50
1.2	10	40	50
1.3	50	40	10
1.4	50	40	10
2	33	33	33

1. Details of Wireless Technologies

In the past, people get connected to each other through wired networks, linked together via physical wires such as copper wires and fiber optics. However, such telecommunication technologies are so spatially limited due to geography and operation cost that new emerging technologies, wireless technologies, are developed to deal with the boundless world of telecommunications.

Wireless technologies are technologies that do not use physical wires as media for communication, but instead make use of electromagnetic waves to convey information. The examples of widely used electromagnetic waves are microwave, radio wave, and infrared transmitted and received with the help of some devices: antennas. Since there are various wireless technologies operated on different backgrounds for different applications, standard organizations have taken a role to standardize them to ensure interoperability. In this report, four wireless technologies will be discussed as follows:

1.1 ZigBee

ZigBee is a technology that enables Wireless Personal Area Network (WPAN)—Personal Area Network that is wireless. It uses low-power radio frequency based on the IEEE 802.15.4 standard to provide low data rate with low power consumption short-distance transmission for specific applications apart from the Internet connection. It is mostly used in embedded applications such as sensors and control devices that consume batteries and do not need high data rate.

Protocol Architectures

ZigBee's protocol architecture is a packet-based protocol that consists of stack layers standardized by 2 organizations: the Institute of Electrical and Electronics Engineers (IEEE) and the ZigBee Alliance. As seen from Figure 1, the IEEE provides the standards only for the Physical (PHY) Layer and the Data Link (DLL) Layer, which is separated into 2 sublayers: the Media Access Control (MAC) Layer and the Logical Link Control (LLC) Layer. Meanwhile, the layers above are standardized by the ZigBee Alliance. The descriptions of each layer are the followings:

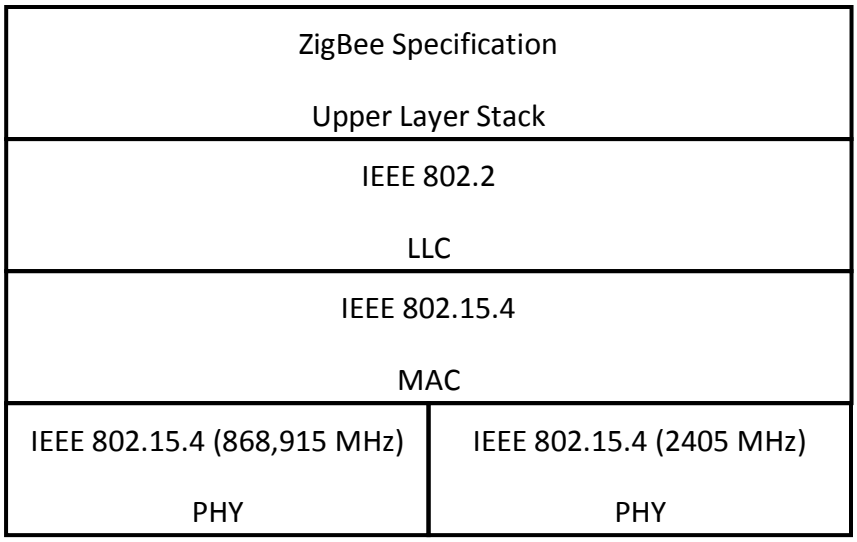

*Figure 1:*ZigBee protocol stack

The PHY Layer of the IEEE 802.15.4 standard operates in 2 separate frequency ranges. Its functionalities are turning radio transceivers on and off, detecting radio frequency signals, analyzing and reporting link quality, selecting channels, checking whether channels are clear and transmitting data.

The MAC Layer is also of the IEEE 802.15.4 standard. Its functionalities are controlling access to radio channels, synchronization, and providing error checking for several topologies without any complexity.

The old version of the IEEE standard for the PHY Layer and the MAC Layer is the IEEE 802.15.4-2003, but the newer version of this standard, IEEE 802.15.4-2006, is also available and accepted by the International Organization for Standardization (ISO) who ratifies the ISO17025.

The LLC Layer is of the IEEE 802.2 standard. Its functionalities are managing data link communication, link addressing,defining service access points,frame sequencing, and supporting other protocol functionalities.

The Upper Layer Stackcontains sublayers whose responsibilities are joining network and device discovery (the Network Layer), and maintaining routing tablesand storing neighbor nodes' information (Application Support Layer).

There are many ZigBee specifications released and under development by the Zigbee Alliance with different characteristics. The examples of them are the ZigBee Home Automation, the ZigBee Smart Energy and the ZigBee Remote Control. Also, many versions of its stack profiles are ZigBee2004, ZigBee2005, ZigBee2006, ZigBee2007, and ZigBee2007 Pro.

In addition, the Radio Frequency for Consumer Electronics (RF4CE) Consortium is the other one who tries to standardize the ZigBee specifications for radio frequency-based remote controls.

Data Transmission

ZigBee is operated in the unlicensed frequency bands called the Industrial, Scientific, and Medical (ISM) bands with different frequencies used in different countries. There are 3 different frequency bands that are used in Europe, the United State of America and Australia, and the other worldwide countries (Table 2). Europe uses the lowest frequency band and frequency, and also bandwidth and data rate are smallest compared to the other two. The USA and Australia use medium frequency band, while the other countries use the highest frequency band, which gives the highest bandwidth and data rate.

*Table 2:*ZigBeedata transmission's characteristics

Country	Europe	USA and Australia	Worldwide countries
Spectrum(MHz)	868-868.6	902-928	2400-2483.5
Frequency (MHz)	868	915	2450
Bandwidth (MHz)	0.6	20	90
Data rate(Kbps)	20	40	250

Transmission media

Transmit power of ZigBee is specified by the ZigBee specifications to be 10, 75, 1500 mW with the minimum transmit power requirement of 1mW. However, the real transmit power is heavily depends on each applications and the conditions of surrounded environment.

*Table 3:*ZigBee transmission media's characteristics

Country	Europe	USA and Australia	Worldwide countries
Transmit power* (dBm)	0	0	0
Receive threshold(dB)	92	92	85
Distance (m)	20	40	250

* Minimum transmit power

ZigBee antennas can be classified into 3 types as follows:monopole antennas, dipole antennas (lowest cost of implementation), and F-Antennas.Here is the example of ZigBee antennas calledFractusEZConnect™ ZigbeeAntennaP/N: FR05-S1-R-0-105(Figure 2). The Fractus EZ connect Zigbee antenna is a rectangular chip shape, using 915 MHz bandwidth. It is a monopole antenna used for indoor and outdoor environment.

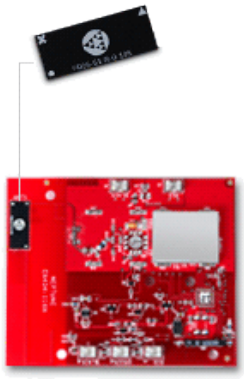

*Figure 2:*FractusEZConnect™ Zigbee Antenna
[http://www.fractus.com/main/fractus/srw_868]

Signal encoding techniques

ZigBee uses the Direct-Sequence Spread Spectrum (DSSS) Coding instead of the normal narrow-band transmission before modulate digital stream to make the radio signal be transmitted over wider range of frequencies and more resistant to interference by expanding codes to be transmitted to be redundant ones. However, the signal modulation techniques used by ZigBee are varied according to the used frequencies. For the frequency of 868 MHz, the Binary Phase Shift Keying (BPSK) is used. Although the BPSK uses 2 phases to encode signals, the DSSS coding replicates each bit to be 15 bits before using the BPSK. For the frequency of 2405 MHz, the Offset Quadrature Phrase shift keying (OQPSK) or the Minimum Shift Keying (MSK) is used. These techniques are similar to the Quadrature Phase Shift Keying (QPSK) but it uses 2 carrier signals whose phrases are different by 90 degree. It modulates some parts of the code on one signal and the others on the other signal. Then, both signals are combined together and transmitted so that one signal element carries 2 bits of data.

Errors

ZigBee has an error detection scheme using the fully Handshaked protocol, which is responsible for the authentication and key exchange. However, it has no error correction scheme so the only way to cope with transmission errors is to do retransmission which is not very good for its system's performance.

Applications

ZigBee is actually designed for the demand of low-cost, low-power-consumption, and low-data rate wireless communications. It is mostly used to form wireless sensor network to monitor and control embedded applications that need batteries to be long-lasting. It can be

used in houses to large buildings such as factories, warehouses, and tall office towers since it can cover quite large area. Typical applications of ZigBee are as follows:

- Home automation control and awareness such as wireless switches for lamps, temperature smart control, and smoke-fire sensor
- Mobile services such as M-healthcare, and M-payment
- Commercial and industrial control such as industrial device control, machine-to-machine communication, automatic meter reading, and access control.

To form a ZigBee network, 3 types of devices called nodes are needed:

1. Coordinator
   Itis a Full Function Device (FFD)that has full functionalities. In each ZigBee network, there can be exactly one Coordinator to establish a network.
2. End Device
   It can be either an FFD or a Reduce Function Device (RFD) that make it a low-powered node. It cannot relay data, but can only talk to their parent nodes.
3. Router
   It is an FFD that relay or pass data from other nodes.

Coordinator and Routers are connected together in a Mesh topology, but end devices are connected to the coordinator or routers in a Star topology. Also, ZigBee supports point-to-point and point-to-multipoint networks.

ZigBee devices are available in market in many forms such as ZigBee module and ZibBee adapters, and ZigBee gateways. ZigBee adapters can provide many connection options to RS-232, RS-485, digital I/O, or analog I/O port. Zigbee gateways allow IP-enable network over Ethernet, cellular, or WLAN. Manufacturers produce integrated radios and microcontrollers (chip) with flash memory or stand-alone components along with software to be used with any processor and microcontroller.

Usage

Since ZigBee is operated on the ISM band, which is reserved and used for license-free communications, having many network technologies worked upon including Zigbee, some bands are only reserved for general use in certain countries and can be used somewhere else for more regulated use. Therefore, ZigBee is now used worldwide but with different operating frequencies. In Thailand, many researchers are studying on how to make use of this technology in the Intelligent Traffic System and tracking system, which are sensor networks that can be applied using ZigBee.

Cost

To implement ZigBee networks needs very low cost compared to other technologies because ZigBee devices consume very little power. ZigBee nodes can mostly in a sleep mode and then activate only when needed to reduce the power consumption. Also, ZigBee end devices are cheaper than coordinators and routers because their functions are restricted resulting in least amount of memory and low cost.

1.2 Bluetooth

Bluetooth is a technology that also enables WPAN. It uses short-wavelength radio frequency based on the IEEE 802.15.1 standard to connect several device simultaneously over a short distance. It is mostly used to transfer files or data among computers and their peripherals with high security.

Protocol Architectures

Bluetooth's protocol architecture is a packet-based protocol with a master-slave structure. One master, which is a node in a network, can communicate up to 7 slaves in a piconet, a network consisting of these 8 devices. More than 2 piconets can be connected to form a scatternet, where one device acts as a master in one piconet and a slave in the other.

The protocol stack of Bluetooth, ratified to the IEEE 802.15.1 standard, is defined by the Bluetooth Special Interest Group (SIG) and contains a number of layers (Figure 3) as follows:

The Physical Radio (RF) Layer is the lowest layer to define and enable radio transmission of transmit power and modulation techniques, convert data into radio signal and transmit by the radio module that contains a transceiver in a single chip.

The Baseband Layer is the layer that manages physical channels and links, handle packets, Does paging, and does inquiry to locate other Bluetooth devices.

The Link Manager Layer has the responsibilities to manage piconets by regulating attachment and detachment of slaves from the master, overseeing the master-slave switch, and establishing different types of links between Bluetooth devices. It also performs security and error correction.

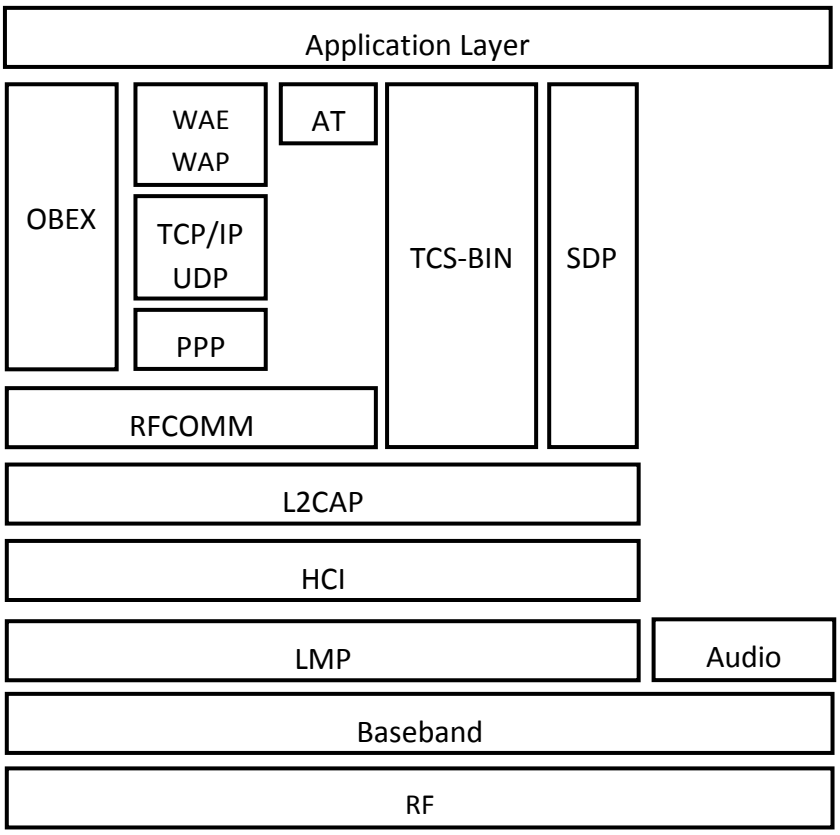

Figure 3: Bluetooth protocol stack

Bluetooth Protocols

Logical Link Control and Adaptation Protocol (L2CAP)has similar functions to the IEEE LLC layer. Its responsibilities are multiplexing multiple connections, segmenting and resembling data packets, and providing retransmission and flow control in the Enhanced Retransmission Mode (ERTM). However, retransmission and flow control is not provided in the Streaming Mode (SM).

Radio Frequency Communications (RFCOMM) Cable Replacement Protocol is responsible for creating a virtual serial data stream, controlling signals over the Bluetooth baseband layer, and providing a simple reliable data stream to users similar to TCP.

Link Management Protocol (LMP)is implemented on controllers and has responsibilities for setting up and controlling Bluetooth links by sending instruction on how to switch from master to slave, performing authentication, and performing encryption.

Service Recovery Protocol (SDP) provides means for applications to discover and publishes services running on top of the Bluetooth stack provided by other devices.

Host/Controller Interface (HCI) is an interface to Bluetooth hardware to standardize communication between the host stack and the controller. Its responsibilities include controller management, link establishment, and maintenance.

Bluetooth Network Encapsulation Protocol (BNEP) is for transferring another protocol stack's data via an L2CAP channel

Audio/Visual Control Transport Protocol (AVCTP) is a protocol that control music player for Bluetooth by transferring AV/C commands over an L2CAP channel.

Audio/Visual Data Transport Protocol (AVDTP) is a telephony control protocol that helps stream music to stereo headsets over an L2CAP channel.

Telephony Control Protocol-Binary (TCS BIN) is optional for establishing voice and data calls between Bluetooth devices of the cordless telephony profile by defining the call control signaling and mobility management procedures.

Adopted Protocols

Point-to-Point Protocol (PPP) is a protocol from the Internet standard to transport IP datagrams over a point-to-point link.

TCP/IP Protocol and UDP Protocol are for packet transmission.

Object Exchange Protocol (OBEX) is a protocol from the sessionlayer.Its responsibilities are object exchanging, and providing a model for object and operation representation to enable wide ranges of devices.

Wireless Application Environment/Wireless Application Protocol (WAE/WAP) is responsible for specifying an application framework for wireless devices (by WAE), and providing mobile users access to telephony and information services (by WAP).

The address scheme of Bluetooth devices is 48-bit IEEE 802 address as a physical address. Apart from that, there are also friendly Bluetooth names for users to easily deal with.

The Bluetooth protocol architecture is the base for the SIG to release many Bluetooth specifications, resulting the following generations of Bluetooth with different characteristics and performances:

- V1.0/v1.0B
    - The earliest versions of Bluetooth specifications
- V1.1
    - The first version standardized under the IEEE 802.15.1-2002 standard

- V1.2
    - The version standardized under the IEEE 802.15.1-2005 standard
    - Introduction of the Adaptive Frequency-Hopping Spread Spectrum(AFH) to minimize interference from IEEE 802.11b WLANs
    - Data rate of 721 kbps
    - Introduction to flow control and retransmission mode for L2CAP
- V2.0+EDR
    - Introduction of the Enhanced Data Rate (EDR) mode instead of the Basic Rate (BR) mode to reacha theoretical data rate of 3 Mbps with a practical data rate of 2.1 Mbps
- V2.1+EDR
    - Introduction of the Extended Inquiry Response(EIR)
- V3.0+HS
    - The attempt to reach a theoretical data rate of24 Mbps by performing high-speed transport not over Bluetooth link itself but over a collocated 802.11 link
- V4.0
    - The version for ultra-low power Bluetooth technology

Data Transmission

Bluetooth is operated on the unlicensed ISM band at the frequency of 2.4 GHz with some differences on the used spectrum in each country. The normal spectrums mostly usedare 2402 to 2480 MHz and 2400 to 2483.5 MHz. However, France uses the spectrum of 2446.5 to 2483.5 MHz and Spain uses the spectrum of 2445 to 2475 MHz, which are the local versions that cannot be interoperable with the international full version. The normal Bluetooth bandwidth is 1 MHz with varied data rates dependent on the modulation techniques applied to each Bluetooth mode (Table 4).

Table 4: Bluetooth's data rate according to different modulation techniques

Modulation technique	GFSK	$\pi/4$ DQPSK	8DPSK	8DPSK
Bluetooth mode	BR mode v1.2	EDR mode v2.0+EDR	EDR mode v2.0+EDR	HS mode v3.0
Data rate(Mbps)	1	2	3	24

Note: Modulation techniques' information is mentioned in *Signal Encoding Technique*

By using short-range radio transmission, Bluetooth can transfer both asynchronous data and synchronous data (voice). Asynchronous data is transferred by using packet switchingvia the Asynchronous Connectionless Link (ACL), which is a point-to-multipoint link between a master and slaves. On the other hand, synchronous data is transferred by using circuit

switching via the Synchronous Connection-Oriented link (SCO), which is a symmetric point-to-point link between a master and each slave. In addition, Bluetooth also has different transmission configurations. Simultaneous transmission is done over 3 channels for voice. Symmetrical data transmission provides same transmission rate for each transmission direction. Symmetrical data transmission provides different transmission rates in each transmission direction. Due to these different configurations to transmit data, the data rate in practical defined by most Bluetooth devices is lower (Table 5) with its maximum value of 723 kbps to a single user. This is because data transmission is occurred in both directions: upstream and downstream.

Table 5: Bluetooth's maximum data rate according to different transmission configurations

Configuration	simultaneous voice transmission	Symmetrical data transmission	Asymmetrical data transmission
Upstream data rate (kbps)	6 per channel	433.99	732.2, 57.6
Downstream data rate (kbps)	6 per channel	433.99	57.6, 732.2

Transmission media

Transmit power of Bluetooth is divided into 3 power classes: 1, 2, and 3. According to Table 6, the power class 1 is the class that has the highest power, so the distance it can reach is also the highest. The power classes 2 and 3 have lower transmit powers and distance respectively.In practice, the distances will be lower than the defined ones because of obstacles such as walls and external interference on radio transmission.

Table 6: Bluetooth transmission media characteristics

Power class	Class 1	Class 2	Class 3
Transmit power (dBm)	20	4	0
Distance (m)	100	10	1

Since Bluetooth devices use radio wave in transmission, they do not have to be at the line of sight of each other. Also, Bluetooth devices usually communicate in a broadcast fashion, so their antennas are omnidirectional ones. Some common types of its antennas are wire monopole, PIFA, helix, and ceramic. Here is the example of Bluetooth antenna called LMX9830 Antenna. Its size is approximately 6 x 9 mm (Figure 4). The transmit power is minimum at -4 dBm and maximum at +3 dBm and the maximum gain setting is -30 dBm.

*Figure 4:*LMX9830 Antenna
[www.national.com/appinfo/.../Bluetooth_Antenna_Design.pdf]

Signal encoding techniques

Bluetooth uses frequency-hopping spread spectrum to chop up the data to be sent and transmits those chunks up to 79 bands. Bluetooth has different signal modulation techniques for each Bluetooth mode. The Gaussian Frequency Shift Keying (GFSK) is used in the BR mode, while the $\pi/4$ DQPSK (Differential Quadrature Phase Shift Keying) or 8DPSK is used in the EDR mode. The GFSK is a variant of the Frequency Shift Keying (FSK) that uses a positive change in the frequency with respect to the previous one to represent the bit 1 and a negative change in the frequency with respect to the previous one to represent the bit 0. The amount that frequency varies is represented by the modulation index, which falls between 280 kHz and 350 kHz. On the other hand, the $\pi/4$ DQPSK or 8DPSK are variants of the combination of the GFSK and the PSK.

Errors

Bluetooth has the Cyclic Redundancy Check (CRC) as its error detection scheme. At the same time, error correction schemes of Bluetooth are also defined by the Link Module. The Forward Error Correction is used for this correction with 2 rate variants. The first variant is the 1/3 rateFEC that repeats every bit 3 times for redundancy. This scheme reduces the data rate(throughput) to be divided by the factor of 3. The other variant is the 2/3 rate FEC that add extra bits to data for correction, which also reduces throughput but enables receivers to detect multiple bit errors and correct a single bit errors without retransmission. Moreover, the Automatic Repeat Request(ARQ) is also used in the error control.

Applications

Bluetooth is used to create wireless personal area networks that allow the exchange of information between digital devices such as faxes, mobile phones, telephones, laptops, personal computers, printers, Global Positioning System (GPS) receivers, digital cameras, and video game consoles to reduce the cabling installation. Devices that are suitable for Bluetooth are the non-resident ones that require short-range data transfer with low bandwidth and low power consumption. The data that can be transferred are, for example, sound between a mobile phone and a headset and files between hand-held computers. The followings are the samples application widely used nowadays.

- Wireless communication and control for mobile phones such as sound transfer between a mobile phone and a hands-free headset, and health sensor data transfer between a mobile phone and medical devices
- Wireless networking between PCs and I/O devices such as mice, keyboards and printers.
- Wireless controller for game consoles such asNintendo's Wii, Sony's PlayStation 3, and PSP Go controllers

- Internet connection
- Replacement of traditional communications such as wired serial communications,infraredcommunications, and dial-up internet access.
- Real-time location systems (RTLS) to track and identify the location of objects in real-time.

In order to communicate with Bluetooth, devices have to support Bluetooth's functionalities. Some devices, such as the MacBook Pro and normal notebooks, are already had built-in Bluetooth cards or embedded with internal notebook Bluetooth cards so that these device can connect to Bluetooth networks without additional implementation. However, other devices that are not yet support Bluetooth have to employ some of these Bluetooth devices: USB Bluetooth adapters, Bluetooth dongles with small amount of software. The operating systemsthat already support Bluetooth are as follows:

- Mac OS X supports Bluetooth v10.2.
- Former Windows supports Bluetooth but needs Bluetooth adapters and drivers.
- Windows XP SP2-SP3 supports Bluetooth1.1, 2.0, 2.0+EDR.
- Windows Vista supports Bluetooth 2.1+EDR.
- Windows 7 supports Bluetooth 2.1+EDR with Extended inquiry response(EIR).
- Linux also supports Bluetooth.

Usage

Bluetooth have been used in many countries but not all interoperable worldwide since some countries such as France and Spain reduce the frequency bands with different hopping algorithms.For Thailand, we usually see the Bluetooth devices in the form of head-sets, mobile phone applications and USB adapters with the same standard of interoperable frequency. Bluetooth devices are very popular because it is cheap, automatic and does not require annoying wires.

Cost

Its cost is quite low because all Bluetooth hardware is contained on a single chip. To make devices function with Bluetooth requires only embedded that chip into the product during manufacturing. There is no need for expensive external devices such as cards at all. Another advantage of Bluetooth over cost is that it is power-saving due to different connection modes.

1.3 Wireless LAN

Wireless LAN is a technology that enables Local Area Network (LAN) in a wireless fashion. It uses radio frequency bands based on the IEEE 802.11 standard to connect client devices over local areas. It is mostly used in the areas where cables cannot reach or cabling installation cost is high.

Protocol Architectures

Wireless LAN protocol architecture is standardized by the IEEE 802.11 standards and the Wi-Fi Alliance is a group of companies who certify interoperable products based on those standards. The IEEE standards verify the wireless LAN protocol stack (Figure) of only the PHY layer and the DLL. The PHY layer is divided into 2 parts: the Physical Layer Convergence Procedure (PLCP) and the Physical Medium Dependent (PMD). The DLL is also divided into 2 parts: the MAC layer and the LLC layer.

The PHY Layer is for transmitting and receiving signals.

The PLCP has responsibilities to reformat data from the MAC layer into frames to send to PMD and determine the medium whether the data can be sent or not.

The PMD has responsibilities to modulate the signals, and translate the binary 1s and 0s of the frames into light pulses for transmission via a series of infrared light.

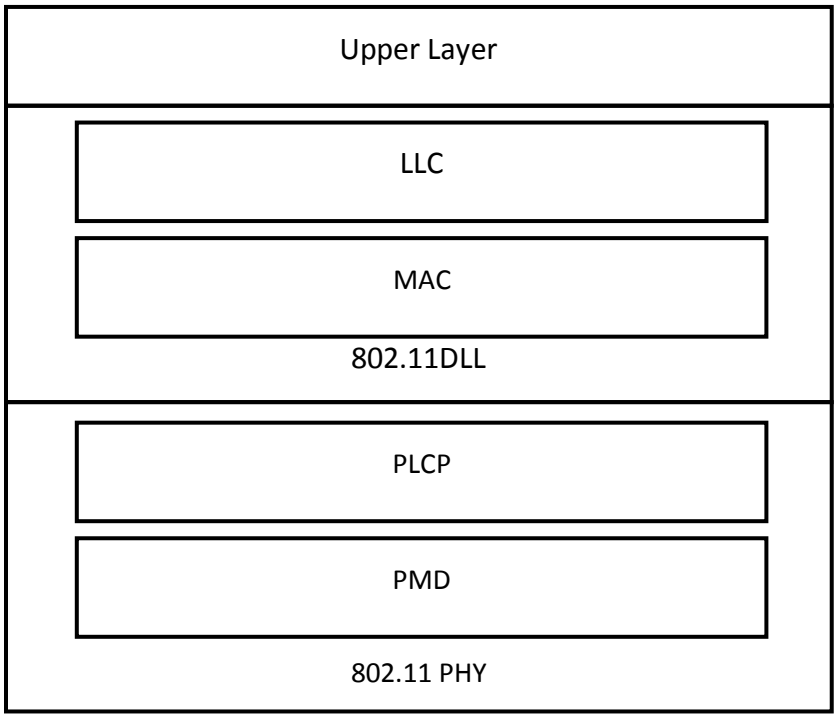

Figure5: Wireless LAN protocol stack

The DLL is for transferring data in a network.

The MAC Layer has responsibilities for hardware addressing and error detection and correction.

The LLC Layer has responsibilities for establishing and maintaining links.

There are many releases of the IEEE 802.11 standard family for wireless LAN, each of which has some changes and differences in characteristics of the PHY layer, the MAC layer, and the LLC layer that improve wireless LAN performances. The following standards: 802.11, 802.11a, 802.11b (802.11 High rate, Wi-Fi), 802.11g, and 802.11n will be discussed in the next sections for each characteristic.

Data Transmission

Wireless LAN uses many schemes of data transmission characteristics according to the standards (Table 7). Two frequency bands used are the ISM band of 2.4 GHz and the Unlicensed National Information Infrastructure (U-NII) band of 5 GHz. The spectrum of both the ISM bandand the U-NII band do not operated consistently worldwide. For the ISM band, the USA and Canada use the spectrum of 2.412-2.462 GHz, Europe uses the spectrum of 2.457-2.472 GHz, France uses the spectrum of 2.462-2.467 GHz, and Spain uses the spectrum of 2.457-2.462

GHz. For the U-NII band, the USA, Europe, and Japan use the spectrum of 5.15-5.25 GHz, while other countries use different spectrums of 5.25-5.35 GHz, 5.47-5.725 GHz, and 5.725.5.825 GHz. The used wireless LAN bandwidths of each standard are quite the same, but the data rates are much different due to the modulation techniques.

Table 7: Wireless LAN data transmission characteristics

Standard	802.11	802.11a	802.11b	802.11g	802.11n
Frequency (GHz)	2.4	5	2.4	2.4	2.4, 5
Bandwidth (MHz)		20	20	20	20, 40
Data rate (Mbps)	1, 2	6, 9, 12, 18, 24, 36, 54	1, 2, 5.5, 11	20-54	100–200

Transmission media

Wireless LAN transmission power is said to be of around 20 dBm (100 mW). However, the maximum amount of power is limited by local regulations in each country and antennas themselves. Apart from that, the distance of wireless LAN is also limited and varied due to the operating frequency and environment's conditions. In fact, the frequency of 2.4 GHz has slightly better than the frequency of 5 GHz and the distance able to be covered by wireless LAN is from meters to kilometers. Here is the example of wireless LAN antennas, whose shape is parabolic. The 5800P9 Parabolic Antenna operates on Frequency Range of 5725-5850 MHz, bandwidth of 125 MHz, and maximum transmit power of 100W.

*Figure 6:*5800P9 Parabolic Antenna
[http://www.antennachina.net/products.asp?sortID=89]

Signal encoding techniques

Wireless LAN employs several encoding techniques to provide different data rates as seen from Table 8.

Table 8: Wireless LAN signal encoding techniques

Standard	802.11	802.11a	802.11b	802.11g	802.11n
Data rate (Mbps)	1, 2	6, 9, 12, 18, 24, 36, 54	1, 2, 5.5, 11	20-54	100–200
Encoding techniques	FHSS, DSSS, 16-PPM, 4-PPM,	OFDM, PSK, QPSK, 16-QAM, 64-QAM,	DSSS, CCK, DBPSK, Differential QPSK	OFDM	OFDM

Frequency Hopping Spread Spectrum (FHSS) is one technique of spread spectrum transmission that uses a range of frequencies in transmission and changes frequencies several times during the transmission. The 16-Pulse Position Modulation (16-PPM) increases the intensity of the current to transmit a series of light impulses at 1Mbps by translating 4 data bits into 16 light impulses. Similarly, the 4-Pulse Position Modulation (4-PPM) increases the intensity of the current to transmit a series of light impulses at 2 Mbps by translating 2 data bits into 4 light impulses. The Orthogonal Frequency Division Multiplexing (OFDM), sending data in parallel via several low-speed channels instead of sending in only one stream, is first introduced to the IEEE802.11a modulation techniques and helps increase the data rate. The Phase Shift Keying (PSK), which changes in the starting point of the wave cycle dependent on bits being transmitted, can give the data rate of 6 Mbps. The QPSK is similar to the PSK but also has a change in amplitude—double the amount of data encoded over the PSK to be 12 Mbps by having one signal sent 2 bits. The Quadrature Amplitude Modulation (QAM) is a combination of the Amplitude Modulation (AM) and the PSK, in which two carriers out of phase by 90 degree are amplitude-modulated but have the same phase. Two variants of the QAMs used in wireless LAN are the 16-level Quadrature Amplitude Shift Keying (16-QAM) which contains 16 different signals and one signal can send 4 bits, and 64-level Quadrature Amplitude Shift Keying (16-QAM) which contains 64 different signals and one signal can send 6 bits. These QAMs can provide higher data rate, but are more complex, more expensive, and more susceptible to interference. Two-level Differential Binary Phase Shift Keying (DBPSK) represents bit 0 with 0-degree phase change and bit 1 with 180-degree phase change, giving the data rate of 1Mbps. The Differential Quadrature Phase Shift Keying uses 4-level phase/amplitude change instead of having only two variations in phase for 0 and 1 so that there are 4 variations in phases for the bits 00,01,10,11 and give the data rate of more than 2 Mbps. The Complementary Code Keying

(CCK) contains a table of 64 8-bit codewords and has 2 variants of 4 bits per signal unit that gives the data rate of 5.5 Mbps, and 8 bits per signal unit that gives the data rate of 11 Mbps.

Errors

Wireless LAN uses parity bits for error detection and the FEC for error correction.

Applications

Wireless LAN is used to create wireless connections in the following applications:

- Home and office device-to-device networks such as communications between personal computers and digital cameras, printer sharing, and network attached storages
- Internet connection through Wi-Fi hotspots such as city-wide Wi-Fi and campus-wide Wi-Fi.
- Reliable data transfer and video and music streaming
- Gaming such as portable gaming devices
- Voice over IP(VoIP) instead of expensive long-distance telephone calls

To form wireless LAN networks, access points and clients which are devices that contain wireless network interface cards (NICS) called stations are grouped to be an infrastructure basic service set. Access points are base stations that transmit and receive radio frequencies for their clients and communicate with other sets. An independent basic service set, however, contains no access points to connect to other sets. Here are some available wireless LAN devices to be used to connect to a network.

Wireless Access Point (WAP)

WAPs act as network hubs that help communicate between wireless devices and a wired device by relaying data between them. A wired device is often an Ethernet hub or switch.

Wireless adapters

Wireless adapters make devices connected to wireless networks. There are many types of adapters according to connection methods, for example, PCI adapters, miniPCI adapters, USB adapters, PC cards, and internal adapter cards that are harder to be installed.

Wireless routers

Wireless routers integrate functionalities of WAPs, Ethernet switches, and internal router firmware applications into one central unit. They allow wired and wireless Ethernet LAN devices to connect to a single WAN device.

Wireless bridges

Wireless bridges' functionalities are very similar to those of WAPs—connect a wired network to a wireless network. However, more than one wired networks can also be connected by using these bridges to prevent loss from an unavailable wired network.

Wireless range-extenders or wireless repeaters

Wireless repeaters are used to extend the range of wireless networks.

Usage

Wireless LAN is widely used worldwide in the forms of Wi-Fi hotspots that provide internet connections. Carnegie Mellon University is first one in the world connecting wireless Internet network at their Pittsburgh campus. Nowadays, even in Thailand, internet users can access to wireless LAN almost everywhere—schools, universities, coffee shops, and along the streets.

Cost

To implement a Wireless LAN network needs quite high cost of hardware and installation. The priceof access points, which are the important device to connect stations together with wired networks, vary by ranging from $300 to $2,000 depending on the features that is again dependent on how large the network will be. Electrical wiring and outlets to power the access points are also needed and a new outlet costs approximately another $250. In addition, after all installation large amount of electrical power will be consumed to receive and transmit enough signal strength, so it costs more money.

1.4 WiMax

WiMax or Worldwide Interoperability for Microwave Access is a technology that enables wireless Metropolitan Area Network (WMAN). It uses high-frequency radio wave to gain a high data rate over long distance that traditional networks are not worth to be implemented. It is used to access the Internet connection almost everywhere worldwide.

Protocol Architectures

WiMax protocol architectures are packet-based similar to other networking standards that only the PHY layer and the MAC layer are differentiated. However, WiMax is very unique in its PHY layer because it supports many frequency bands and modulation techniques with respect to environment conditions. WiMax protocol stack can be seen from Figure 7.

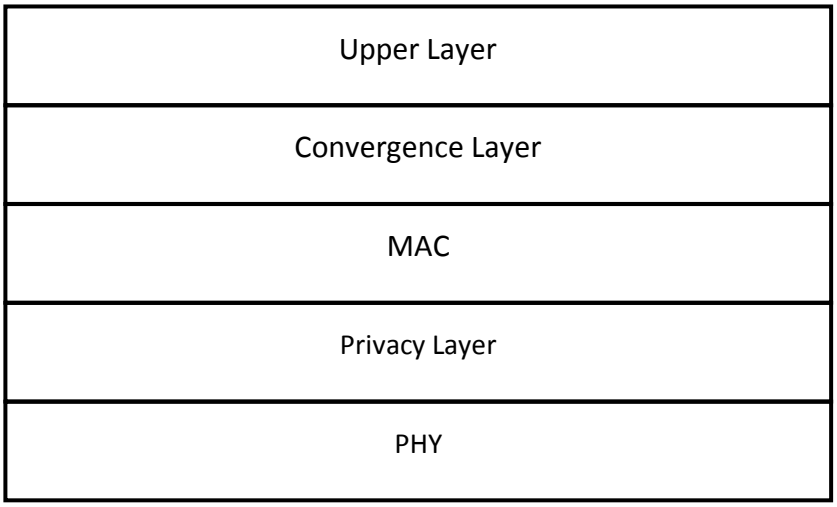

*Figure7:*WiMax protocol stack

The PHY layer is of the IEEE 802.16 standard and has the similar functionalities to normal PHY layers—encoding and decoding signals, transmitting bits, ranging, and controlling power. The exception property that the PHY layers of other network technologies do not have is that it supports multiple frequency bands and modulation techniques by dynamically changing them for different requirements of different characteristics of each network. Also, the IEEE 802.16 standard allows many variants of this layer in terms of the operating frequency to conform to each country's regulations.

The MAC layer is common to all countries and is connection-oriented. Its responsibilities are packetizing frames, disassembling frames, do fragmentation, performing error detection and ARQ, controlling Quality of Service (QoS) and controlling access to medium to provide point-to-multipoint broadband access.

The Service-Specific/MAC Convergence Layer provides interfaces to upper layers by mapping a service to a connection for multiple simultaneous services on the same link and for multiple protocols in the same network, and map upper layer addresses into the IEEE 802.16 48-bit addresses.

The Privacy sublayer is for authentication, encryption, and key exchanges for privacy and security of a connection.

The WiMax Forum, along with the WiMAX Spectrum Owners Alliance (WiSOA) who merged with Wireless Broadband Alliance to deploy WiMax spectrum, has been released many standards of the family IEEE 802.16 with increasing development as follows:

- IEEE 802.16-2001
  - The early version of WiMax
  - Non-supported mobility
  - Fixed point-to-multipoint broadband network
  - Frequency band of 10-66 GHz
- IEEE 802.16-2004/802.16d/ Fixed WiMax
  - Non-supported mobility
  - OFDM256
  - Fixed point-to-multipoint broadband network
- 802.16a
  - Frequency band of 2 -11GHz
- 802.16c
  - Clarification for performance evaluation and testing
- IEEE 802.16.2-2004
  - Implementation practice to enable coexistence with other 802.16 network with minimum interference
- IEEE 802.16-2005/ 802.16e/ Mobile WiMax
  - Supported mobility
  - Data rate up to 2 Mbps for portable devices slowly moving or stationary
  - Data rate up to 320 Kbps for fast-moving vehicles
  - Scalable OFDMA (SOFDMA)
  - Adaptive Antenna Systems (AAS) which is the advanced antenna diversity schemes
  - Hybrid Automatic Repeat-Request (HARQ)
  - MIMO technology
  - Introduction of the Low-Density Parity Check (LDPC)

Apart from the IEEE standards, WiMax is also included in the IMT-2000 set of standards by the Radio communication Sector of the International Telecommunication Union (ITU-R).

Data Transmission

WiMax is operated on the U-NII band. However, there are no uniform global licensed spectrums for WiMax, so the WiMAX Forum has published three licensed spectrum profiles for Asia at 2.3 GHz, the USA at 2.5 GHz, Pakistan at 3.5 GHz, and India and Indonesia at a mix of 2.5 GHz, 3.3 GHz and other frequencies. The bandwidth of Wimax is specified by the standards to be either 3.5 MHz, 5 MHz, 7 MHz, or 10 MHz for the fixed WiMax. For the mobile WiMax, the bandwidth can be either 5 MHz, 8.75 MHz and 10 MHz. WiMax's data transmission characteristics can be seen from Table 9.

Table 9: WiMax's data transmission characteristics

Frequency (GHz)	1.5 licensed	5.8 unlicensed
Spectrum (GHz)	2-11	10-66
Bandwidth(MHz)	3.5	20
Data rate (Mbps)	70	120

In practical, the maximum achievable data rate depends on many parameters: modulation techniques, bandwidths, and the FEC coding rate. QAM gives more data rate than QPSK and BPSK respectively. The higher bandwidth is used, the more data rate is. Also, the higher coding rate is used, the more data rate is. The data rate is also higher if users are closer to the cell tower.

Transmission media

WiMax transmission power and transmission distance are varied in very wide ranges. This is because of the different in operating frequencies.Normally, transmit power of WiMax is from 100mW up to 2W. Also, the distance of transmission depends on many factors such as the data rate and the line-of-sight technology between base stations and subscriber stations. At the data rate of 70 Mbps, WiMax can have a range up to 48 km. Here is the example of WiMax antenna called 3.5GHz WiMAX MIMO Patch Antennas SPX-020ASFW9. It is a directional outdoor antenna, whose gain is 14 dBi operating at the frequency from 3.3-3.8GHz.

Figure 8: WiMAX MIMO Patch Antennas SPX-020ASFW9
[http://www.manufacturers.com.tw/showroom-8615-4-5-0000082773-0.php]

Signal encoding techniques

There are 5 modulation techniques used by WiMax to reach different data rate: BPSK, QPSK, 16-QAM, 64-QAM, and 256-QAM, which give high to low data rate respectively. Although the higher data rate can be offered by QAM, PSK is more robust. It also uses OFDM and Orthogonal Frequency Division Multiple Access (OFDMA), which subdivides frequency channels into many subcarriers.

Errors

For the error detection of WiMax, the Low-Density Parity Check (LDPC), an error correcting code for transmitting a message over a noisy transmission channel, is used. Sometimes the CRC is also used as an option in the MAC frame.

WiMax employs several FEC schemes to correct transmission error. The used FECs have different coding rate that affects transmission performance. Therefore, the best coding rate is selected according to the used modulation techniques to overcome overhead of the FEC without retransmission so that transmission speed is optimized (Table 10).

Table 10: FEC schemes used with different modulation techniques

Modulation technique	FEC coding rate
BPSK	1/2, 3/4
QPSK	1/2,2/3,3/4,5/6,7/8
16-QAM	1/2,3/4
64-QAM	2/3,5/6
256-QAM	3/4,7/8

Wimax also performs the Hybrid Automatic Repeat-Request (HARQ), which is a combination of forward error-correcting coding and error detection using the ARQ.

Applications

Thanks to WiMax bandwidth and range, it is used for networking over very large area and long distance that traditional networking is not efficient to be implemented. The example of WiMax applications are listed as follows:

- Broadband mobile internet access across countries or cities as an alternative to traditional cables and DSL, which are more expensive
- Alternatives back-hauls with more substantial bandwidth for cellular operations instead of using copper wires, microwave links, or satellites
- Triple-play services by supporting TV (video), telephone(voice), and data on the same network such as VoIP(Voice over IP) and IPTV
- Machine-to-machine communications such as Smart Metering

To connect to WiMax, numerous devices known as subscriber units (SUs) in the market are available.

WiMAX gateways

WiMax gateways,providing VoIP, Ethernet and, WiFi connectivity, are divided into 2 categories: an indoor version and an outdoor version. Indoor WiMax gateways are usually placed near windows to gain the best WiMax signal nearest to the WiMax base station, while outdootWiMax gateways need installation the same as satellite dishes.

WiMAX dongles

WiMax USB dongles have omnidirectional antennas that have quite low gain. They are eeused in portable fashion by plugging them to mobile computers where areas are good-coverage of WiMax signals.

WiMAX Mobile Phone

WiMax-enabled mobile phones are also available but not very widespread. These mobile phones support 3G and 4G technologies and can be used under the areas covered by WiMax networks.

Usage

In Thailand, WiMax has not been so popular to normal users yet because the WiMax frequency band is now occupied by military sections. However, WiMax is under the study to be used in Thailand, started from WiMax networking for rural-area students by Mea FahLuang University.

In other countries, WiMax have been rapidly deployed due to its special characteristics while Yota is announced to be the largest WiMAX network operator in the world.Dominantly, WiMax is used to assist communications in areas affected by natural disasters. After the tsunami in Aceh, Idonesia in 2004, WiMax played an important role to make communication between inside and outside the area possible even with almost all destroyed infrastructure. Also, VoIP for the area affected by Hurricane Katrina was provided by WiMax.

Cost

The overall cost to implement WiMax is quite low because installation cost can be reduced. Only antennas to mount to base stations are needed without other required configurations from the service providers. The service providers can also remotely manage devices, which reduce maintenance cost.

2. Comparisons of Wireless Technologies

ZigBee, Bluetooth, Wireless LAN, and WiMax are all wireless technologies, but are created for different purposes. Therefore, they are different in both the technical aspect and the practical aspect. The followings are the comparisons among these 4 technologies:

Technical Aspect

Protocol architectures of all of them arelayered stacks containing protocols that are standardized by the standard organizations. The main standards are defined for the lower layer of the stack protocols, while upper layers apart from the PHY layer and the DDL can be adopted from somewhere else. These main standards for wireless technologies are of the IEEE 802 family by the IEEE. Besides, each technology also has organizations that promotes it and certifies products if they conform to certain standards of interoperability (Table 11).

Table 11: IEEE standards and organizations

Technology	ZigBee	Bluetooth	Wireless LAN	WiMax
IEEE standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.11	IEEE 802.16
Organization	ZigBee Alliance	Bluetooth SIG	Wi-Fi Alliance	WiMax Forum

ZigBee, Bluetooth, and Wireless LAN operate on the ISM band of 2.4 GHz, whereas wireless LAN also operates on the U-NII band of 5 GHz. Meanwhile, WiMax operates on non-uniform bands. Higher frequency of 5 GHz has the advantages that it helps provide higher data rate, but its disadvantage is that the system will become more complex and expensive. Similarly, the more bandwidth is, the more data rate can be reached, but with complexity and high cost. In addition, large bandwidth also increases the chances of errors at the receivers, too. Transmission media of all technologies are antennas, which have unique characteristics of transmit power, receive threshold, gain, shape and size, and distance designated by manufacturers to conform to the standards. More transmit power, receive threshold, and gain give longer distance of transmission. The data transmission parameters' characteristics of each technology are as shown in Table12.

Table 12: Data transmission parameters

Technology	ZigBee	Bluetooth	Wireless LAN	WiMax
Spectrum	ISM	ISM	ISM, U-NII	No uniform band
Frequency(MHz)	2400	2400	2400, 5000	2300-3300
Bandwidth	low	low-high	low-high	high
Transmit power	low	low-high	low-high	high
distance	short	short	medium	long

Each technology tries to transmit digital data over analog signal, which is radio wave. Different signal encoding techniques are applied to each technology and one technology also has a number of techniques to vary the data rate as required. It is important that the best encoding technique that provides the highest data rate is not always the best solution since it may result in more interference sensitivity of the signal and overhead to cope with bit errors may reduce the overall throughput.

There are 4 commons schemes to deal with errors of transmission:error detection, error correction, ARQ, and retransmission without mentioned means. ZigBee is very simple that it relies on only retransmission, which does not make ZigBee's performance so bad since the transmission is over short range. However, Bluetooth, wireless LAN, and WiMax have some means to cope with overhead from retransmission, for example, by using the CRC, the FEC, and the ARQ. Although implementing these means produces more data to be transmitted, the trade-off that it is better than retransmission the data over a long distance can be tolerated.

Practical Aspect

ZigBee, Bluetooth, wireless LAN, and WiMax are different in terms of network size they can cover. ZigBee and Bluetooth are for small areas (personal areas). Wireless LAN is for a bit larger areas (local areas) and WiMax is for large areas (metropolitan areas). Therefore, their applications, usages, and costs are dependent on transmission ranges as shown in Table 13.

Table 13: Practical aspect to use wireless technologies

Technology	ZigBee	Bluetooth	Wireless LAN	WiMax
Application	ZigBee device is used for monitors because of low-power - consumption, hence it can stay in a long period of time.	Application for Bluetooth usually comes in the form of non-wired headphones, mobile phone applications and USB link adapters.	Applications of Wireless LAN is used for communication networks such as WAP, Mobile phone application.	WiMAX are designed as a complimentary technology to Wi-Fi and Bluetooth. They use for communication widely more than wireless LAN.
Usage	They are being used in Thailand and also in other countries. Bandwidth of 2.4 GHz is used worldwide except in Europe and America.	They are being used in Thailand and also for other countries. The normal standard Bluetooth bandwidth is 2.4 GHz which is used in all countries except France and Spain.	They are being used in Thailand and also for other countries. It broadcasts in the 5 GHz frequency.	They are being used in Thailand and also for other countries. the frequency bands between 2 and 6 GHz
Cost	ZigBee is the low-power and low-cost wireless devices. The cost is approximately 100-2000 Baht up for Thailand.	The cost of Bluetooth depends on which devices, but approximately 1000 Baht up.	Cost of Wireless LAN equipment is around 1,800 Baht up.	Cost of WIMAX is around 1800 - 4000 Baht

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