ITS323 Assignment I

Comparison of Wireless Technologies

Prepared by

Group 20

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Bluetooth

Bluetooth is a prevalently-used and low-power-consuming wireless technology for a connection over short distances, usually between two handheld mobile devices, or a mobile devices and a PC.

1) Protocol Architectures

- **Layered Stacks**

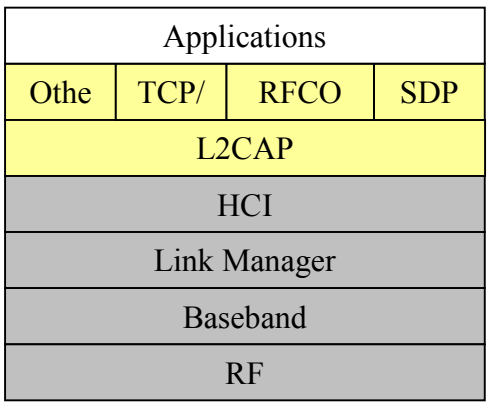

Figure 1.1: Simplified Bluetooth Layered Stack

According to Figure 1.1, this layered stack of Bluetooth enables devices to locate each other and establish a connection for exchanging data and interacting with one another. The gray layers are **transport layers**. The following are a brief explanation of each layer from bottom to top:

RF (Radio Frequency layer) is the lowest layer specifying Bluetooth device to use the 2.4GHz ISM band. (ISM is abbreviation of *Industrial, Scientific and Medical*)

Baseband is the Bluetooth physical layer managing physical channels and cooperating with the *Link Manager* for achieving link connection.

Link Manager is responsible for link setup by searching and connecting other Link Managers via the *Link Manager Protocol (LMP)*.

HCI (Host Controller Interface) is a transport layer functioning as a basic interface between the host stack, i.e. OS, and the hardware, i.e. the Bluetooth IC. The examples of HCI are USB and UART.

Each layer, except HCI transport layer, is a separate entity so every layer is replaceable or easy to change.

- **Protocols**

Elementary protocols appearing in all Bluetooth stacks are: *LMP*, *L2CAP* and *SDP*. These protocols are included in Figure 1.1 as the light-yellow layer since they are **middleware** layers (Middleware is software connecting its component and applications). The following are an explanation of each middleware layer:

LMP (Link Manager Protocol) is the protocol that handles link establishment between Bluetooth devices by cooperating with *Link Manager*.

L2CAP (Logical Link Control and Adaptation Protocol) is a Bluetooth communication protocol implementing multiplexing data between different higher level protocols. L2CAP relies on a baseband link.

SDP (Service Discovery Protocol) is a protocol that handles discovery of services in the top layer of the stack, provided by other devices.

- **Standards and Standard Organizations**

The Bluetooth technology uses an IEEE 802.15.1 standard. Its standard organization is Bluetooth Special Interest Group (SIG), the non-profit and privately-held association. Leaders in various industries relating to the usage of Bluetooth are members of SIG. Its core activity is publishing Bluetooth specifications, protecting the trademarks and promoting the use of this technology.

2) Data Transmission

This technology uses the unlicensed ISM band between 2.4 and 2.485GHz and uses a radio frequency of 2.45GHz for communication and connection. The band used by Bluetooth is in microwave frequency band (300MHz-300GHz). Its bandwidth equals to 720Kbps.

Bluetooth has three main versions: Bluetooth v1.0, Bluetooth v2.0, Bluetooth v3.0. The version 1.0 gives the maximum data rate of 1Mbps while the version 2 with EDR (Extended Data Rate) feature can achieve the maximum data rate of 3Mbps. The version 3.0 with HS feature can achieve the data rate of 24Mbps.

3) Transmission Media

Three power classes of Bluetooth are classified by the maximum power output. Class 1 has maximum transmit power of 100 mW or 20 dBm, Class 2 has the maximum transmit power of 2.5mW or 4 dBm, and Class 3 has the maximum transmit power of 1 mW or 0 dBm. Approximate distance range of Class 1, Class 2, and Class 3 are 100m, 10m, and 1m respectively. The receive threshold of Bluetooth is at -70dBm.

Antennas of Bluetooth come in various shapes hinging on the specification of Bluetooth products. However, this report describes features of some example antennas. For instance, 2.45 GHz ISM-band antenna for Bluetooth and WLAN IEEE 802.11b (Surface-mount ceramic multilayer) of Phycomp has center frequency of 2.45, 2.60 and 2.70 GHz; bandwidth of 100 MHz, and antenna gain of 0 dBi maximum. Its shape is long shape.

Another example is GS-BT2416C1.H Bluetooth® class 1 module of ST company has transmit power of 18 to 20dBm and receive threshold of -84dBm while GS-BT2416C2 Bluetooth® class 2 module of ST Company has transmit power of 0dBm and receive threshold of -74dBm.

4) Signal Encoding Techniques

The signal encoding technique of Bluetooth is **Gaussian frequency-shift keying (GFSK)**. GFSK is a type of FSK modulation, a signal encoding scheme representing digital data in analog signal by using different frequencies. GFSK is similar to FSK except it uses a Gaussian filter to smooth frequency deviations. Gaussian filtering is one of approaches for reducing the spectral width by making the pulse change gradually. For example, a pulse shifting from -1 to 1 is changed to -1,-.98,-.93 … .96, .99, and 1 instead, for spectral efficiency.

5) Errors

- **Error Detection and Correction**

Bluetooth signal is often interfered by electromagnetic noises so it requires error-detection and error-correction. For error-detection, Bluetooth uses various calculations. And three error-correction schemes are used in Bluetooth system:

- 1/3 rate **forward error correction (FEC)**,
- 2/3 rate **FEC**, and
- **Automatic repeat request (ARQ)**.

FEC is an error-correction scheme without requiring extra data from the transmitter. This scheme can avoid inefficiency from retransmissions since wireless application has high error rate and thus require many retransmissions. FEC is aimed to reduce number of retransmissions. However, in a quite error-free environment, overhead from FEC reduces the throughput. 1/3 of FEC is used to protect important information in the header.

Automatic Repeat Request (ARQ) or Automatic Repeat Query, is an error-control method that uses acknowledgements (messages sent from receiver to transmitter to inform the correctness of transmitted data) and timeouts (valid time intervals for receiving ACK). ACK indicates whether to retransmit data.

WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is wireless broadband technology providing mobile internet access with high data rates.

1) Protocol Architectures

- **Layered Stacks**

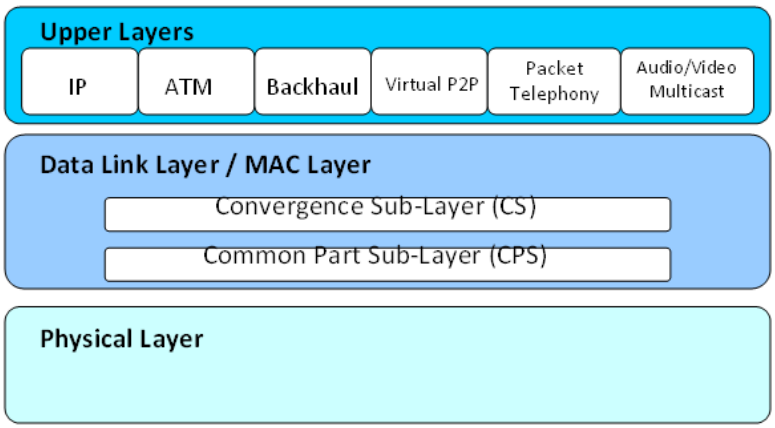

Figure 2.1: WiMAX Layered Stack

According to Figure 4.1, Wimax layered stack consists of three main layers: Upper Layers, MAC Layer, and Physical Layer. Upper layers are application layers. In the lowest layer of stack, **PHY (Physical) Layer** of WiMAX/IEEE 802.16 standard (a basis of WiMAX) supports working with the line-of-sight 10-66 GHz and no-line-of-sight 2-11 GHz bands. (Line of Sight or LOS is an electromagnetic radiation travelling in a straight line.)

MAC (Medium Access Control) Layer, compared to Data Link Layer of OSI model due to similarities of function, is connection-oriented and provides a connection between *Upper Layers* and *PHY Layer*. This layer is made of three sublayers: the CS (Convergence Sublayer), the CPS (Common Part Sublayer) and the Security Sublayer. It is a MAC with a scheduling algorithm, which means each client is given a time interval to communicate with the access point.

- ***Common Part Sublayer (CPS)*** is responsible for bandwidth allocation, connection establishment, maintenance of the connection.

- ***Convergence Sublayer (CS)***, located above the MAC CPS sublayer, uses service provided by CPS and processes upper layers.

- **Standards and Standard Organizations**

The WiMAX technology uses an *IEEE 802.16 standard*. Its standard organization is WiMAX Forum, a non-profit *organization* formed to certify and promote usage of wireless products using the *IEEE 802.16* standard. Another task is standardization of products. Products can obtain the "WiMAX Forum Certified" designation, which can be sealed on products, if they pass the WiMAX Forum's testing. Apart from the WiMAX Forum, there is another standard organization, named IEEE 802.16 Working Group, that create standards for broadband wireless access,

2) Data Transmission

This technology uses the licensed no-line-of-sight band at 2 to 11GHz (only in *IEEE 802.16a* standard, the modification of *IEEE 802.16* standard), and unlicensed line-of-sight band at 10 to 66 GHz. It uses a frequency of 2.5GHz and 3.5GHz. For the data rates, WiMAX has data rate up to 40Mbps in indoor environment but can reach a maximum data rate of 75 Mbps.

3) Transmission Media

This broadband technology has a distance range of 48km. It has a transmit power of 199.52 mW or +23dBm. The antenna used by WiMAX is the Point-to-Point type. Example antenna is MT-30044 ANTENNA with a minimum gain of 18dBi and it is a directional subscriber.

4) Signal Encoding Techniques

WiMAX 's signal encoding technique of is **Quaternary Phase Shift Keying (QPSK)** and **Quadrature Amplitude Modulation (QAM).** QPSK has higher tolerance to interference over long distances than QAM

QPSK is signal encoding techniques which represent digital data by analog signals. It uses four points, on the constellation diagram, having the same length of distance from the center of a circle of constellation diagram. Each point has different phases. Each phase is used to represent the symbol. QPSK can only encode two bits per symbol. QPSK differs from BPSK (Binary PSK) in that QPSK has four phases to represent each two bits of data while BPSK has two phases to represent each one bit of data and QPSK has stonger signal than BPSK due to higher number of bits.

5) Errors

- **Error Detection and Correction**

WiMAX technology has built-in error detection schemes. Convolutional Encoding, Strong Reed Solomon FEC, and interleaving algorithms are used to detect and correct errors.

Reed Solomon FEC is

- **ARQ**

WiMAX uses **Hybrid Automatic Repeat Request (HARQ)**, implemented in the *IEEE 802.16* MAC Layer. HARQ uses a retransmission scheme as in ARQ error-control method, combining with a Forward Error Correction (FEC) code to enhance reliability in data transmission.

Wireless LAN

Wireless LAN is a flexible data communication system using electromagnetic waves, to transmit and receive data. This technology provides data connectivity without requiring user to be at only a fixed point, or, in other word, enables movable LANs.

1) Protocol Architectures

- **Layered Stacks**

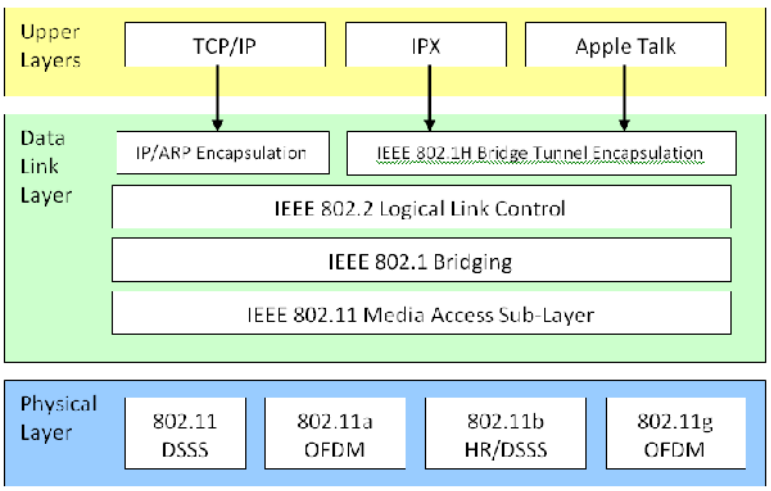

Figure 3.1: Layered Stack of Wireless LAN

Layers implemented in IEEE 802.11 standard are Data link layer (MAC) and Physical layer.

1. Medium Access Control (MAC) layer sets a rule about when each node on the network can send message. IEEE 802.2 Logical Link Control (LLC) layer, a component of MAC layer, provides a connection-oriented service (a logical link) between nodes. MAC Layer of wireless LAN is contention based. This means that all clients using the same access point are competing for bandwidth.

2. Physical layer (PHY) layers based on which standard of IEEE 802.11 family is used. The used standard specifies frequency band that physical layer connects to. For instance, if 802.11a standard is used, physical layer must connect to 5GHz ISM band.

- **Standards and Standard Organizations**

Wireless LAN covers the *IEEE 802.11* family. The standard organization of Wireless LAN is **Wi-Fi Alliance**. Wi-Fi Alliance is an association aiming at promoting usage of Wireless LAN technology. Moreover, it is responsible for certifying products if they can meet the interoperability requirements.

2) Data Transmission

There are many standards in an 802.11 family, such as 802.11, 802.11a, 802.11b, and 802.11g.

The **802.11** standard gives data rate of only 1Mbps and has bandwidth of 1 or 2Mbps. The speed of this standard is too slow for most applications.

The **802.11a** standard can achieve data rate of 54Mbps and has bandwidth up to 54Mbps. This standard has the fast maximum speed which is beneficial to data transmission. However, its signal is easily impeded due to shorter range of signal.

The **802.11b** standard**,** referred to as 802.11 High Rate or Wi-Fi, gives data rate of 11Mbps and has bandwidth of 1, 2, 5.5, and 11Mbps. This standard's signal is not easily impeded.

The **802.11g** standard gives data rate of 54Mbps and has bandwidth of 54Mbps. It has fast maximum speed and its signal range is not easily impeded.

All of the mentioned standards uses a 2.4GHz frequency band except 802.11a, using a 5GHz frequency band. The 802.11a standard is not interfered by microwave ovens and Bluetooth since it doesn't use the 2.4GHz band.

3) Transmission Media

Distance range of wireless LAN is 15-150m for indoor applications and 300m for outdoor applications. Wireless LAN signals can traverse distances of 100m to 300m. By swapping the standard omni-directional antennas with directional antennas, these distances can be improved up to between 2 KM to 4 KM. Wireless links using 2.4GHz equipment and dish antennas have achieved distances up to 50 KM.

Normally, wireless LANs use a directional antenna designed for outdoor use and usage in the unlicensed ISM band. Types of antennas are designed to commensurate various weather conditions, signal distances and bandwidths. The goal of the design is to increase reliability by narrowing the beam and focusing transmit power to the destination to increase signal strength and SNR.

4) Signal Encoding Techniques

There are many signal encoding techniques depending on the standard. For example, the 802.11 standard uses DSSS. The signal encoding technique of 802.11 standard of Wireless LAN is **Direct-Sequence Spread Spectrum** (**DSSS**).

DSSS is a modulation technique. Direct sequence spread spectrum combines a data signal at the sending station with a higher data rate bit sequence or a chipping code. This scheme causes higher signal-to-noise ratio (SNR) on the channel which is called *process gain*. Procedures of DSSS can be found on *http://en.wikipedia.org/wiki /Direct-sequence_spread_spectrum*

5) Errors

- **Error Detection**

Each station checks incoming data for altered bits by using CRC algorithm. If destination station does not detect errors, it sends an ACK back to the source station. Otherwise, the data link protocol ensures that the source station resend the packet.

Error detection algorithm of Wireless LAN is the **Cyclic Redundancy Check (CRC)**. Firstly, the system computes a frame-check sequence (FCS), a binary number sequence, for each frame of data. When the data arrive, the program re-computes. If the divisor can divide without having a remainder, the error does not occur. However, if there is a remainder, the system detects the error and subsequently uses ARQ to enable retransmission of data frame.

- **ARQ** (As same as explained in ARQ of the Section 1: Bluetooth)

ZigBee

Zigbee is a low data rate, low power consumption, low cost, wireless protocol expected to provide low cost and low power connectivity for equipment that needs a year-long battery life, e.g. remote controller, requiring low to moderate data rates.

1) Protocol Architectures

- **Layered Stacks**

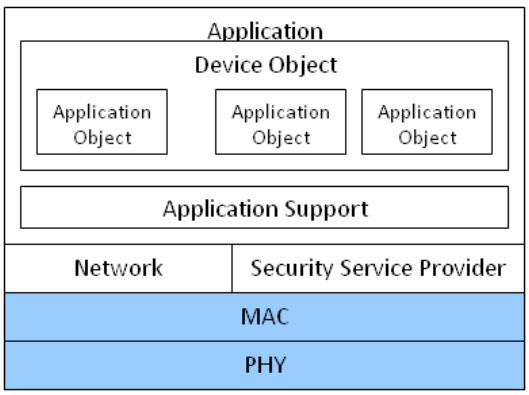

Figure 4.1: Layered Stack of ZigBee

According to Figure 4.1, the blue layers are defined in *IEEE standard 802.15.4* and the white layers are implemented in ZigBee. This technology uses the Physical Layer and MAC Layer of *IEEE 802.15.4.*

The PHY Layer provides two services: the PHY data service and PHY management service. The MAC sub-layer provides two services: the MAC data service and the MAC management service.

- **Standards and Standard Organizations**

The Zigbee technology uses an IEEE 802.15.4-2003 standard. Its standard organization is ZigBee Alliance, which maintains and publishes ZigBee standards.

2) Data Transmission

The ZigBee technology uses the unlicensed radio frequency band between 2.45 and 2.4835 GHz. There are three versions of ZigBee frequency bands used in different countries, which are a global band, North American band, and European band.

The global band has a frequency of 2.4GHz, and a data rate of 250Kbps. The North American band has a frequency of 915 MHz, and a data rate of 40Kbps. The European band has a frequency of 868 MHz, and a data rate of 20Kbps. And Zigbee technology has bandwidth ranging from 20 to 250Kbps.

Among three of them, the global band has the highest data rates which is good for data transmission since it can transmit higher number of bits in a second than the others.

3) Transmission Media

Distance range of ZigBee ranges from 10 to 75m. This wireless technology has transmit power of 0dBm or 1mW. There are many Zigbee's antenna options, such as chip antenna, whip antenna, and U.FL. RF connector.

Receiver sensitivities are -85dBm for 2.4GHz and -92dBm for 868/915MHz.

For the example of ZigBee product, cc420 2.4 GHz IEEE 802.15.4 / ZigBee-ready RF Transceiver, of Chipcon Products from Texas Instruments, has a transmit power ranging between -3 and 0dBm and receive threshold ranging between -95 and -90dBm

4) Signal Encoding Techniques

The signal encoding technique of ZigBee is **Offset-Quadrature Phase-Shift Keying (O-QPSK) modulation**. O-QPSK is a modification of QPSK modulation, using four different values of the phase to represent a digital signal. Since large amplitude fluctuations in QPSK worsens quality of communication systems, offsetting the timing of the odd and even bits by one bit-period is required to alter the jumping of phase in symbol construction and therefore give lower amplitude fluctuations than non-offset QPSK [1].

5) Errors

- **Error Correction and Error Detection**

ZigBee uses **FEC (Forward Error Correction)**, as its error correction scheme. FEC is capable of both correcting and detecting the error. FEC uses codeword to represent data and as an error checker. The system transmits codeword instead of real data frame. If the received codeword is different from the transmitted codeword, error is detected.

Comparison

1) Protocol Architectures

	Bluetooth	ZigBee	WLAN	WiMax
Standards:	IEEE 802.15.1	IEEE 802.15.4-2006	IEEE 802.11	IEEE 802.16
Standard Organization:	- Bluetooth Special Interest Group (SIG)	- Zigbee Alliance	- Wi-Fi Alliance	- WiMAX Forum

Table 5.1 Standards and Standard Organizations of Bluetooth, ZigBee, Wireless LAN, and WiMAX

According to the types of MAC defined in layered stacks of WiMax and wireless LAN, WiMAX has a MAC with a scheduling algorithm while Wireless LAN has a contention-based MAC. Therefore, WiMax provides better quality of bandwidth distribution compared to Wireless LAN since clients do not have to compete with each other for bandwidth.

2) Data Transmission

Wireless Technology	Bluetooth			ZigBee	WLAN				WiMax
Standards/ Versions	Bluetooth 1.0	Bluetooth 2.0	Bluetooth 3.0		802.11	802.11a	802.11b	802.11g	
Spectrum	The unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz			The unlicensed radio frequency (RF) at 2.45 to 2.4835 GHz band					The licensed band at 2 to 11 GHz, and unlicensed band at 10 to 66 GHz
Frequency	2.45 GHz			2.4GHz Global, 915MHz Americas, 868 MHz Europe	2.4 GHz	5GHz	2.4 GHz	2.4 GHz	2.5, 3.5 GHz
Data Rates	1 Mbps	3 Mbps	24 Mbps	250kbps at 2.4GHz, 40kbps at 915MHz, 20kbps at 868MHz	1 Mbps	54 Mbps	11 Mbps	54 Mbps	Up to 40 Mbps(indoor) Maximum of 75 Mbps
Bandwidth	720 Kbps			20-250 Kbps	1 or 2 Mbps	up to 54 Mbps	1, 2, 5.5 and 11 Mbps	54 Mbps	

Table 5.2: Comparison of Spectrum, Frequency, Data Rates, and Bandwidth

Among the four wireless technologies, WiMAX has the highest data rates of 75 Mbps. This is beneficial since it has highest data capacity that it can send per second. Bluetooth has generally lower data rates than those of wireless LANs since Bluetooth does not require high bandwidth due to low amount of transmitted data.

3) Transmission Media

	Bluetooth	ZigBee	WLAN	WiMax
Distance (m):	1-100	10-75	15-150 (indoor) 300 (outdoor)	48 km
Transmit power	1, 2.5, 100 mW	1 mW	1 W (US) 100 mW (Europe)	199.52 mW or 23 dBm

Table 5.3: Comparison of Distance and Transmit Power

Among four wireless technologies, Wireless LAN has the longest distance which is an advantage for application which requires far transmission distance and mobility of users. Bluetooth is designed for communication between two devices only, it range is only few meters. While in wireless LAN, a greater range allows greater mobility.

For transmit power, four technologies have similar transmit power. However, some types of Bluetooth and Wireless LAN in Europe have higher transmit power. The higher the transmit power is the stronger the signal and the lower the chance of errors. Therefore, some versions of Bluetooth and Wireless LAN have stronger signal strength and lower error rates.

The antenna of Zigbee and Bluetooth are embeded inside the device, but Wireless and WiMAX need to use the antenna for seperating the signal around.

4) Signal Encoding Technique and Errors

	Bluetooth	WiMAX	WLAN	ZigBee
Signal Encoding Technique	GFSK	QPSK	DSSS	O-QPSK
Error detection & correction	FEC	FEC	CRC	FEC
ARQ	ARQ	ARQ	HARQ	

Table 5. 4: Comparison of Signal Encoding Technique, Error Detection, Error Correction and ARQ

6) Applications

Most common application of **Bluetooth** is **cable replacement**. Many devices use Bluetooth in order to be wireless and eliminate the needs of cables. The examples of these devices are headsets, mice, and syncing between a PC and a phone.

Main application of **ZigBee** is embedding in the device that requires low power consumption and low data transfer rate wireless connection. The devices are part of "Wireless Sensor Network". Examples of devices are industrial sensor and smoke detector.

7) Usage

Because of this, the number of devices that have Bluetooth far outnumber those that have wireless LAN. Almost all phones and laptops that have wireless capabilities also have Bluetooth in them. Bluetooth is more widespread compared to wireless LAN. Wireless LANs are used prevalently in Thailand.

8) Cost

Wireless LAN is far more expensive than Bluetooth and Bluetooth is cheaper in aspect of implementation than wireless LAN. The prevalence of Bluetooth may cause very low cost of Bluetooth devices which are cheaper than wireless LAN devices. In aspect of cost, Bluetooth is more reachable technology for communication between smart phones.

The price of Zigbee is also cheap.

The cost of just only the Zigbee chip is cheap, but after combine into many device could cost a lot of price, such as Sound detector, sensor, etc.

9) Summary

- **Advantages of Each Technologies**

Zigbee has a power-saving and has a cheap cost due to low maintenance cost since the battery is depleted after a year-long period.

Bluetooth is prevalently used. This means repairing can be easily done.

Wireless has high mobility and accessibility from anywhere due to long distance range.

WiMAX has long distance range which makes it highly accessible and high data rates which makes high speed transmission.

- **Disadvantages of Each Technologies**

Zigbee has short distance and a low speed.

Bluetooth is that its signal can be interfered easily by the wireless signal.

Wireless has a lot of standard that can cause the problem in the combine usage. Wireless LAN also has high cost.

WiMAX is not prevalently used in Thailand. Thus, there is a limited number of device that WiMAX can connect to.

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