

# Comparing Modern Wireless Technologies

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## Wireless Technologies Covered

- Zigbee
- Bluetooth
- Wifi
- WiMAX

ITS 323 Data Communications - Assignment 1

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## Contents

Abstract .....	5
Table 1: Group Contribution .....	5
1.0 - Zigbee .....	6
Introduction .....	7
ZigBee Devices .....	7
ZigBee Networking.....	8
ZigBee Layered Stack .....	10
ZigBee Data Transmission .....	12
ZigBee Transmission Media .....	13
Signal Encoding Techniques .....	14
Frequencies & Modulation: .....	14
Errors .....	15
ZigBee Applications.....	16
Usage .....	17
Cost.....	17
2.0 - Bluetooth .....	19
Introduction to Bluetooth Technology.....	20
Protocol Architecture of Bluetooth.....	20
Bluetooth Data Transmission - Frequency .....	21
Data Rate .....	22
Antenna and Power Specifications .....	22
Signal Encoding.....	23
Error Handling.....	24
Application.....	24
Usage & Costs .....	25
Conclusion .....	25
3.0 - Wi-Fi (Wireless Lan) .....	26
Introduction .....	27
Wi-Fi Protocols.....	27
Data Transmission & Transmission Media: .....	28

Modulation Techniques ..... 28

Error Handling..... 29

Applications ..... 29

Usage ..... 29

Costs ..... 29

4.0 - WiMAX (Worldwide Interopability for Microwave Access) ..... 30

    Introduction: ..... 31

    Protocol Architecture:..... 31

    Signal Encoding Technology:..... 31

    Data Transmission..... 32

    Transmission Media ..... 32

    Errors ..... 33

    Applications ..... 33

    Usage ..... 33

    Cost..... 33

Wireless Technology Comparision ..... 34

Bibliography..... 37

    Bluetooth Bibliography ..... 38

    WiMAX Bibliography ..... 38

    Zigbee Bibliography ..... 38

    Wi-Fi Bibliography..... 39

## 2.0 -Abstract & Group Participation

## Abstract

This report will discuss thoroughly the four most currently used wireless technologies (Zigbee, Bluetooth, Wifi, and WiMAX) In terms of each of their architectures, data transmission methods, signal encoding schemes, error handling, and modern applications and uses. Each technology will be discussed technically followed by brief discussion of their contributions to real and daily life. The goal is to establish a broad understanding of each of these technologies and its applications in order to be able to make viable comparisons between them and contribute relevant ideas regarding their uses.

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**Table 1: Group Contribution**

	<b>Sweta Dwivedi</b>	<b>Taskinul Haque</b>	<b>Timon Dressler</b>
<b>Zigbee</b>	100%	-	-
<b>Bluetooth</b>	-	100%	-
<b>Wifi</b>	33%	33%	33%
<b>WiMAX</b>	-	-	100%
<b>Discussion</b>	33%	33%	33%

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# 1.0 - Zigbee

## Introduction

ZigBee is a standard for wireless communication protocols that was founded to allow communication between devices that require less power consumption, long battery life and cost effectiveness and can work with low data rates at the same time.

The ZigBee standards also allow different devices to interoperate with each other. Devices which are built on the requirements specified above.

ZigBee protocol foundation is based on the IEEE 802.15.4 – 2003 (2006) + standards.

ZigBee was developed as most of the existing technologies such as Bluetooth and Wi-Fi provided high data rates but weren't needed for applications that depended on long battery life and less power consumption. Example: Sensors and Controls.

## ZigBee Devices

There are 3 main types of ZigBee devices:

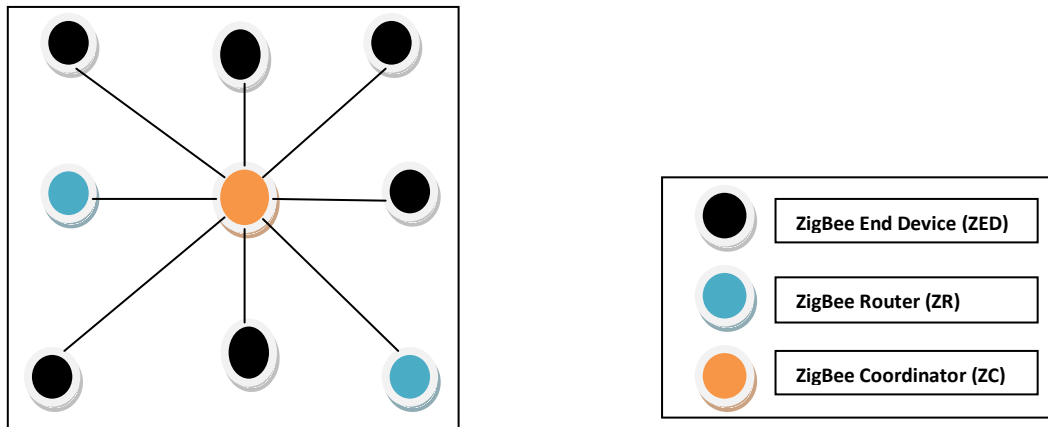
1. ZigBee Coordinator (ZC)  
The ZigBee Coordinator (ZC) has the primary task to create, manage and connect networks of ZigBee devices. The ZigBee coordinator also shares most of its tasks with the ZigBee router and acts as a router majority of the period.
2. ZigBee Router (ZR)  
The ZigBee Router (ZR) also manages network, routes the data and adds new nodes to the network.
3. ZigBee End Device (ZED)  
The ZigBee End Device (ZED) usually collects data and sends it to its parent nodes (ZC or ZR), requests to join or leave a network and switches to a mode (active / sleep).  
Active mode: ZED is set to active mode while sending or receiving message.  
Sleep mode: ZED is set to sleep mode when not being used, for a longer battery life.

## ZigBee Networking

The networks formed by the ZigBee devices are referred to as Wireless Personal Area Networks (WPANs) as the communication between ZigBee devices are short ranged. Typically when a network is created by the ZigBee Coordinator (ZC), a network ID assigned to that network which is also known as PAN ID.

ZigBee networking supports 3 different Topologies; Star Topology, Tree Topology and Mesh Topology.

### Star Topology

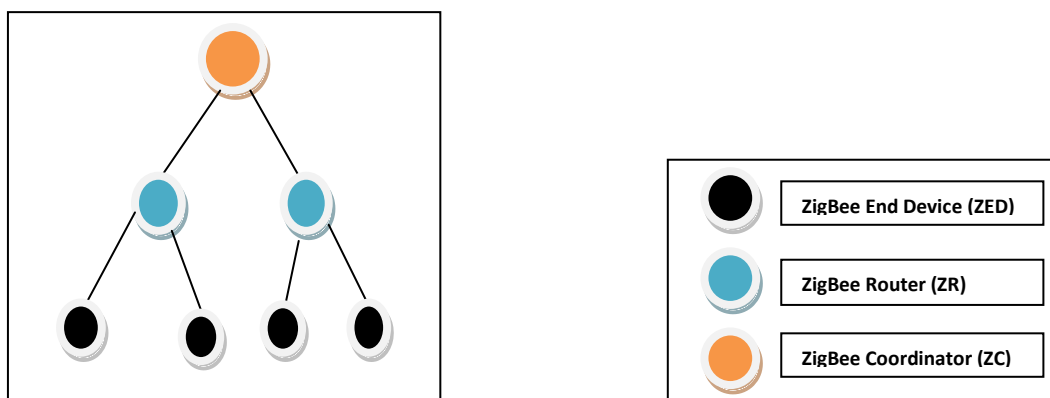


In the Star Topology, the ZigBee End Devices can communicate with each other by sending their data via a ZigBee communicator.

The Coordinator is the central hub in this form of network; Provides isolation of the ZigBee End Devices and solves the purpose of keeping the tasks of ZigBee End devices to a minimum for achieving a low cost and power consumption.

The ZigBee Router can also be connected as one of the terminals to the ZigBee Coordinator.

### Tree Topology

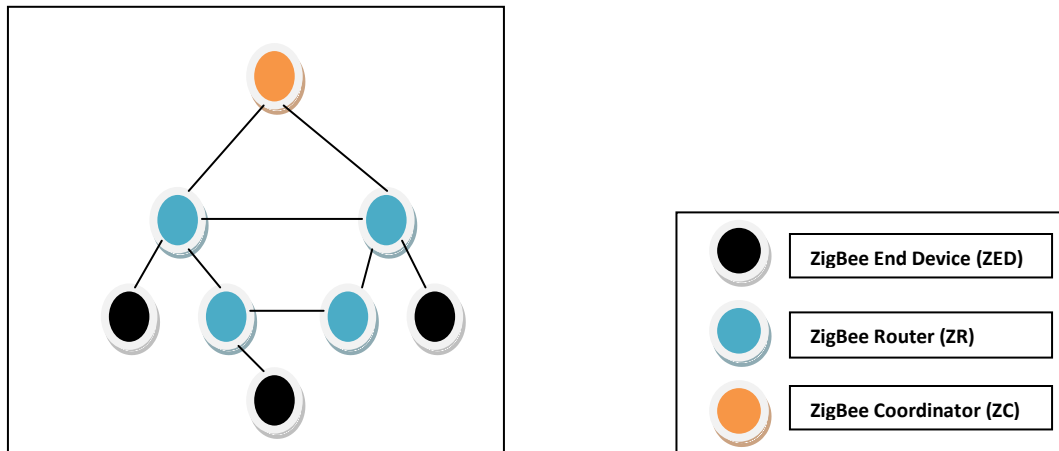




In the Tree topology, the root of the tree is always the ZigBee Coordinator (ZC), the child of the root can be either a router (ZR) or the end device (ZED), In order for one ZigBee End Device to communicate with another ZigBee end device the message has to pass via the parent node.

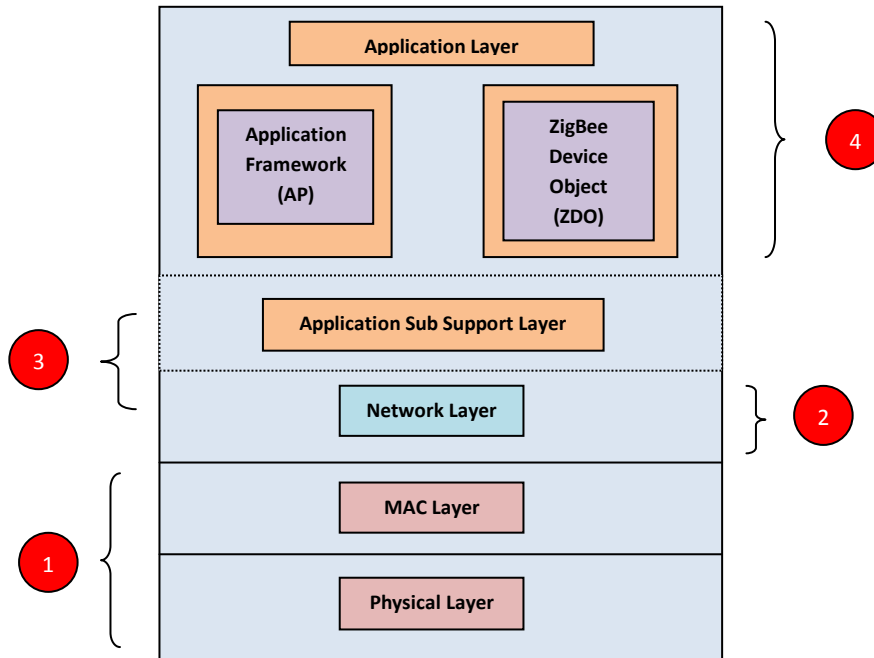
In this type of topology, the ZigBee end devices should not be the parent nodes, as they have really minimum functionality to provide longer lasting battery, also because 2 end-devices cannot communicate directly.

### Mesh Topology



The mesh topology is almost the same as the tree topology, but the 2 different child nodes can directly communicate with each other without having to traverse through the parent node. The router gets the opportunity to send the message even if one of the links leading to the child node fails or incase there is a lot of traffic on a particular link.

## ZigBee Layered Stack:



### 1. Physical Layer & Media Access Control Layer

Standard Organization: IEEE (Institute for Electrical and Electronic Engineers)

Standard: IEEE 802.15.4 – 2003 (2006) †

Physical Layer

Protocol: Carrier Sense Multiple Access With Collision Avoidance (CSMA/CA)

MAC Layer

### 2. Network Layer

Standard Organization: ZigBee Alliance

Standard: ZigBee Standard

Protocol: ADOV (Ad Hoc On Demand Distance Vector)

### Network Layer tasks for Device Type:

- **ZigBee Coordinator (ZC)**
  - Creating a network
  - Choosing the best frequency available for forming a network
  - Allocating addresses to new nodes joining the network
  - Discovery of networks
  - Routing the data
  - Finding the best paths.
- **ZigBee Router (ZR):** Allocating address, routing the data and finding the best path, allocating address for a new node joining the network.

- ZigBee End Device (ZED): Joining/Leaving network, Sending Data to parent node (ZC or ZR), changing modes.

### 3. Application Sub-support Layer

Standard Organization: ZigBee Alliance

Standard: ZigBee Standard.

#### The Application sub-support layer:

The application sub-support layer does the task of Binding and Discovery.

**Binding:** Binding is the process of keeping the address of two corresponding devices via matching their cluster ID's through a binding table. Hence, the binding table stores the cluster ID for this application object attribute and matches it with another application object that would use this attribute. (Ex. Light Bulb & Light Sensors)

The Binding tables are kept by ZigBee Coordinators (ZC) and ZigBee routers (ZR).

The binding table actually stores the address of the source device and its endpoint with the matching destination device and the corresponding endpoint.

**Discovery:** Discovers other devices within the range or Personal Area Network.

### 4. Application Layer

Standard organization: ZigBee Alliance

Standard: ZigBee standards

Protocol: ZDO (ZigBee device object)

Application Layer:

The application layer contains Application Framework and ZigBee device Object.

**Application Framework:** The application framework is the space at which the *application object* is described.

It also allows the applications to send and receive data.

Application object: The application object is defined by the manufacturer. It defines the actual object and services provided by the application.

**ZigBee Device Object:** The ZigBee device object has the job of defining the type and roles of the ZigBee device. (Ex. ZigBee Coordinator (ZC), ZigBee router (ZR) & ZigBee End device (ZED))

ZigBee Device object responds to the binding requests.

ZigBee device object also implements security.

### ZigBee Data Transmission

The Physical layer specified by the IEEE 802.15.4 – 2006 standards implemented in ZigBee stack protocol works on:

- 3 Frequencies : 868 / 915 / 2450
- 3 Modulation Techniques: Binary Phase Shift Key (BPSK), Amplitude Shift Keying (ASK) & Offset Quadrature phase-shift keying (O-QPSK)
- The combination of frequencies with different modulation techniques can result in different data rates
- The frequencies 868/915 MHz can implement one of the 3 modulation techniques where as frequency 2450 MHz can only implement the O-QPSK modulation technique.

Frequency (MHz)	Spectrum (MHz)	Bandwidth (MHz)	Modulation	Data Rate (kb/s)
868 (American)	868 – 868.6	0.6	BPSK ASQ O-QPSK	20 250 100
915 (European)	902 – 928	26	BPSK ASQ O-QPSK	40 250 250
2450 (World wide)	2400 – 2483.5	83.5	O-QPSK	250

## ZigBee Transmission Media

The IEEE 802.15.4 standard protocol specifies the estimate values of receive sensitivity on frequencies implemented by the devices.

Frequency (MHz)	Modulation	Receive Sensitivity (dBm)
<b>2450</b>	O - QPSK	-85
<b>868/915</b>	O - QPSK	-85
<b>868/915</b>	ASK	-85
<b>868/915</b>	BPSK	-92

The table below shows the ZigBee devices and their transmission specifications.

### ZigBee Devices

Device	Antenna	Transmit Power (mW / dBm)	Receive Threshold (dBm)	Distance (m) (Indoor/Outdoor)
<b>XBee-Pro® ZB Wall Router</b>	Internal	50 / +17 or 10 / +10	-102	90 / 1600 or 60 / 750*
<b>XBee® ZB* (End Device, Coordinator)</b>	PCB(embedded), U.FL & RF pad	3.1 / +5 Or 6.3 / +8 (B.M)	-100 / -102 (B.M)	60/1200
<b>Motion Detector (End Device)</b>	Internal	2.8/ 4.5	-97	30.48
<b>ETRX2 ZigBee Module* (End Device, Router or Coordinator)</b>	Integrated ceramic antenna, Hirose U.FL coaxial connector or single port 50Ω pad	2/+3 or 3/ +5	-98	-

\*B.M = Boost Mode.

\*The module can act as an End device, Router or Coordinator and does not contain any antenna but an external antenna needs be attached to it. The antenna specified are optional, any one of these can be used with the module.

## Signal Encoding Techniques

In ZigBee devices the signal modulation techniques are specified by the PHY layer of the IEEE 802.15.4 standard.

According to the IEEE standards the modulation is done in 3 basic steps.

1. Bit-to-Symbol mapping.  
The data is mapped from the decimal value to its equivalent binary representation.
2. Symbol-to-Chip mapping.  
Once the binary value (Symbol) is obtained the symbols are further mapped to chip values.
3. Modulation.  
According to the modulation technique used by frequencies, the modulator converts the chip values into analog signals.

The standard allows the ZigBee devices to operate on a set of frequencies.

Each different set of frequencies can have different set of modulation techniques

### Frequencies & Modulation:

- Frequency: 868/915 MHz  
Modulation: Binary Phase Shift Keying (BPSK)
- Frequency: 868/915 MHz  
Modulation: Amplitude Phase Shift Keying (APSK)
- Frequency: 868/915 MHz  
Modulation: Offset Quadrature Phase Shift Keying (O-QPSK)\*\
- Frequency: 2450 MHz  
Modulation: Offset Quadrature Phase Shift Keying (O-QPSK)\*

#### \* Offset Quadrature Phase Shift Keying (O - QPSK):

The chip values obtained by symbol-to-chip mapping, is divided into 2 signal parts, I and Q.

The (I) signal component contains the first bit of chip value and the (Q) signal component contains the second subsequent bit that follows. Hence the output (modulated) signal will be the mapping of I & Q signal every half symbol of the Q signal.

## Errors

The IEEE 802.15.4 standard specifies that the devices should contain a packet error rate less than 1%. Based on assumption one of the possible error correction and detection methods used by the ZigBee devices is Forward Error Correction.

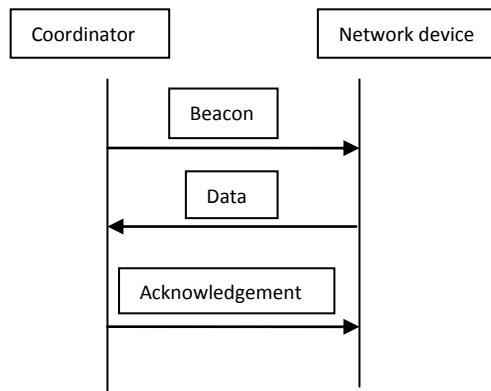
## ARQ

### Data transmission

As defined by the IEEE standards, there can be 2 types of data transfer in a network.

#### ➤ Beacon enabled

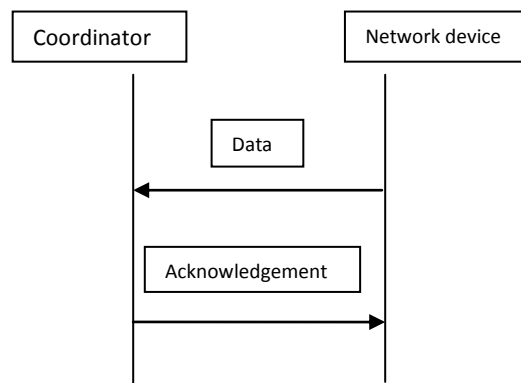
For communication between a coordinator and network device, the network device has to wait for a beacon frame from the coordinator, once received then the data and acknowledgement frames can be transferred by the communicating devices.



#### ➤ Non-beacon enabled

In a non-beacon enabled Personal Area network, the communicating devices can directly request or send data and acknowledgement frames without having to wait for a beacon frame to be sent from a coordinator.

Beacon enabled Personal area networks are the networks that require synchronization and support for low latency device such as PC peripherals whereas the non-beacon enabled Personal area network do not really require synchronization.



## ZigBee Applications

### What scenario's /applications are they intended for?

ZigBee devices are intended for applications that require low data rates and long battery sustainability.

There are numerous applications for ZigBee device.

- Home automation systems  
Central remote system for managing different house-hold appliances. Such as lights, Television, Air conditioners etc.
- Security systems  
Using sensors to detect the opening of doors and attaching them to alarms.
- Keeping record of data (electricity, temperature)  
Attaching devices to electric meter to keep track of electricity usage or temperature etc.
- Telecommunications  
Broadcasting advertisements within the ZigBee device range.

The Application of ZigBee isn't limited to only these areas. There can be even wider use of ZigBee according to the needs of the user.

In one example, ZigBee is used as a part of the Tsunami warning system: Pressure Sensor design.

Why ZigBee for such a project?

- Mesh Topology allows nodes to connect to each other and form a bigger network, even though the communication is short ranged.
- Supports long battery life for devices like sensors.

ZigBee started defining new communication standards for sensor and controls.

How would the technology used by a typical user?

A typical user can use it for many purposes as mentioned above or could be programmed according the needs of the user by using a ZigBee module such as XBee-PRO ZB Programmable Dev Kit.

What are the devices needed?

The devices needed could be ZigBee end devices and a router for managing a few devices.

Else, if there are a lot of devices that need to communicate with each other, a network can be set up using ZigBee coordinators.



## Usage:

ZigBee hasn't completely become conventional in Thailand, although there are a few implementation of ZigBee for certain projects.

There is a Thai company called SYNERGY, which does sell ZigBee modules but not specifically products that implement ZigBee.

(SYNERGY: <http://www.synes.co.th/products.html> )

In countries like U.K., there is a higher implementation of ZigBee. For example AlertME. AlertME is a company that creates a range of Smart Home Energy Management products

OKI is a leading Japanese telecommunication company, it produces ZigBee usb modules that can be used for advertising within a personal area network.

## Cost

Requirement for setting up a simple ZigBee network:

Device	Cost *
ZigBee Router	2000 – 3000 ฿
ZigBee Coordinator	200 - 300 ฿
ZigBee End Device	1000 – 1500 ฿
ZigBee Module	1000 – 1500 ฿

The ZigBee end devices cannot communicate with each other directly, so either a router or a coordinator is always needed for a small network.

The Router and Coordinator will not last on a battery, they need to be powered directly as these two devices need to be awake most of the times.

Another cost that could be included would be the battery for ZigBee end devices but since they last for a long time, the cost incurred will be very less or insignificant.

\*The prices may differ. This is just a rough estimate of the cost.

\*Revised standards

\*P.S: All the diagrams are created by me but one of the diagram may look exactly the same as given on specification because it cannot be further simplified.



## 2.0 - Bluetooth

## Introduction to Bluetooth Technology

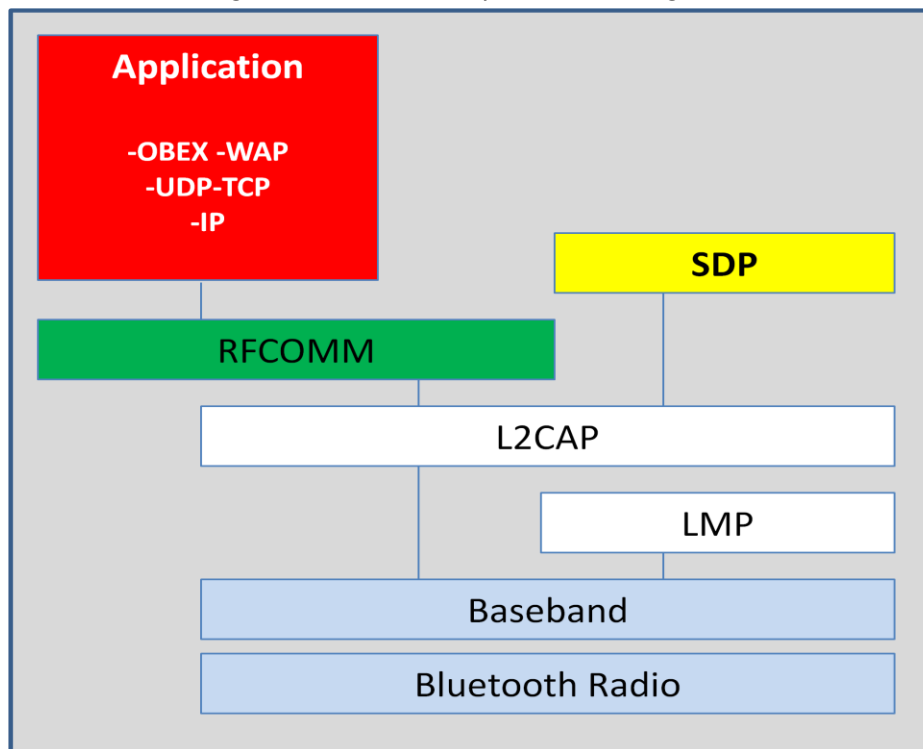
Similar technology originally developed in the early 1940's by the US military, later standardized by Ericsson (Swedish corporation) in 1994. Bluetooth itself is a wireless technology *standard* for short range communications. This wireless transmission technology was intended to replace cables between communicating interfaces within a short proximity but expanded into wide use for inter connecting devices.

Each Bluetooth device can be connected to seven other devices simultaneously, when multiple devices are paired/connected to each other they form a piconet or a Personal Area Network PAN. A device in the connection (Master) can transmit data to one other device (Slave) within the piconet at a time, simultaneous transmissions can be established but are rare )Master, Slave can switch at any time).

## Protocol Architecture of Bluetooth

In Practice, all layers of the Bluetooth Architecture is difficult to define, but in a simplified approach to the layered protocol stack of Bluetooth can be defined by the following, in ascending order. . . .

Figure 3.1 - Protocol Layered Stack Diagram



## Radio layer

Carries definitions for a Bluetooth transceiver, operational sensitivity levels, and the protocol to adopt frequency hopping (*refer to Bluetooth Data Transmissions*)

## Base band

This layer forms the physical radio frequency link between devices, and is responsible for ensuring that the communicating devices are synchronized to a common clock and frequency hopping pattern, through and to ensure the stability of a connection through addressing, channel control, and flow control to retain synchronous data transfers (data/voice packets)

## Link Manager Protocol

The Link Manager LM, Has the task of enforcing security; device discovery, authentication, and encryption as well as handling the establishment, modification, and usage of logical links, through communicating with other devices' LM layers within proximity. (*communicate using LMP*)

## L2CAP - Logical link control and Adaptation Protocol

This layer manages logical links and provides data services to higher level layers by performing tasks like segmentation, multiplexing and reassembling received packets as well as providing QoS Quality of Service to devices requesting it.

## RFCOMM

An important protocol designed to emulate transmission as if the communication was taking place over a RS232 wired interface (*Serving Bluetooth's original purpose, Cable replacement*); so applications are more widely supported, based on the **ETSI Standard, TS 07.10**.

## Service Discovery Protocol

Responsible for allowing applications to query various available services provided by other Bluetooth enabled Devices: its essential in order to establish connections between these devices.

## Bluetooth Data Transmission - Frequency

Data is broadcasted using a (semi) isotropic antenna, and the 2.4 GHz **ISM band** (frequency range = 2.402-2.480 GHz) , utilizing *frequency hopping* to avoid interference from devices transmitting similar range of frequencies. Frequency hopping through spread spectrum FHSS, is the transmission of data through a variety of frequencies at specific predetermined times; there are 79 possible frequencies, separated by 1Mhz levels , which Bluetooth devices can transmit. The frequency hopping pattern is pseudorandom and determined algorithmically, where all intercommunicating devices must be synchronized to a common, clock and frequency hopping pattern. In addition, the hopping pattern is dynamic; can be set to avoid frequencies which are currently being used by other devices in proximity, to further avoid interference.

## Data Rate

In terms of Data rate we discuss the Basic Rate and a Enhanced Data Rate BR/EDR, BR has a bit rate of 1 Mb/s where as EDR has a bit rate of up to 3Mb/s. The difference between BR/EDR is essentially the implementation of different modulation methods. [refer to ***Signal Encoding*** for more details]

BR uses a modified version of Frequency Shift Keying FSK, known as Gaussian Frequency Shift Keying GFSK, whereas, EDR implements Phase Shift Keying. Bluetooth is unique, as it uses BR/EDR simultaneously but for different cases; BR transmits the access code, and Packet Headers, as EDR transmits the payload and trailer sequences.

## Antenna and Power Specifications

**Table 3.2 – Power Classes<sup>1</sup>**

Power Class	Maximum Output Power	Nominal Output Power	Minimum Output Power
<b>Class 1</b>	100 mW (20 dBm)	N/A	1 mW (0 dBm)
<b>Class 2</b>	2.5 mW (4 dBm)	1mW (0 dBm)	0.25 mW (-6 dBm)
<b>Class 3</b>	1 mW (0 dBm)	N/A	N/A

Class 1 devices, were designed to communicate over a long range (<100m), Class 2 devices which are most commonly used domestically (<10m) and Class 3 devices for minimum distances (<1m). Inter communicating devices must determine each of the other devices' lower and upper receive power thresholds (in order to avoid overwhelming or damaging the receiving device); the Receiver Signal Strength Indicator RSSI is responsible for this task and the transmitted power is controlled by the LMP. Thus, transmitted power can be adjusted by the devices itself as long as it complies with its class specifications.

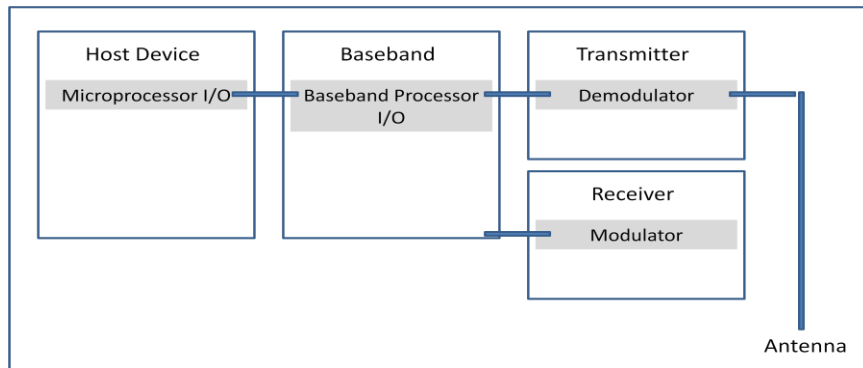
In terms of the sensitivity specifications of a Bluetooth device, it is actually outlined that a receiver can have any sensitivity as long as the Bit Error Rate BER is less than 0.1%. This however, normally means that a device have a receiver sensitivity of minimum -70dBm and better (below).

<sup>1</sup> Bluetooth Core V4.0, Volume 2 – Core System Package, Radio, Table 3.1

### Signal Encoding

The sequence of data transmission is as follows (refer to Figure 3.3), a host device such as a cell phone or notebook will transfer digital signals to the Bluetooth Baseband, where the transmitter will modulate the signal onto a Carrier Frequency. When the signal is received by the end device, the signal must be demodulated and sent back to the host(s) of the end device(s) as digital data.

Figure 3.3 - Data Transmission procedure



As afore mentioned, Bluetooth uses two different modulation techniques; Firstly, Gaussian Frequency Shift Keying GFSK. GFSK is similar to the standard frequency shift keying where each specific frequency represents a designated bit or bit pattern, GFSK however, calculates deviations between two consecutive frequencies, where a negative deviation will represent a logical binary zero value and a positive deviation will represent a logical binary one value.

Secondly, the implementations of Phase Shift Keying PSK. Where the phase of a modulated signal is shifted to represent data, or in this case rotated. The equations to consider are out of scope for this course but the phase shifts representing each bit are identified in the Table 3.4 below.

Table 3.4 - Phase shifts Representing Bit Combinations<sup>2</sup>

B1	B2	Phase Shift (k)
0	0	$\pi/4$
0	1	$3\pi/4$
1	1	$-3\pi/4$
1	0	$-\pi/4$

<sup>2</sup> Bluetooth Core V4.0, Volume 2 – Core System Package, Radio Specification, Table 3.4, DQPSK mapping

## Error Handling

Although the Bluetooth specifications are brief and vague about error handling techniques, the Bluetooth baseband implements Forward Error Correction FEC, which allows errors to be corrected by the receiver instead of forcing retransmission. The transmitting device assigns a unique code word to a specific bit pattern, using a FEC encoder. If an error occurred the received code word is assumed to be the most similar to the one transmitted by comparison, then decoded. FEC will most likely detect and correct errors, but in some cases it detects the error but assumes a different code word (not corrected), and in very rare cases it will neither detect or correct the error. The trade of being in any case, additional data must be transmitted to implement FEC as the codeword's are generally larger than the original message therefore reducing throughput, larger codeword's provide better error handling but at the same time further decrease throughput.

In addition Bluetooth also implements Automatic-repeat-request ARQ. which waits to receive an acknowledgement indicating the receiver has successfully received the packet, if no acknowledgement is received after a timeout period the sender will retransmit its data. Using ARQ and FEC simultaneously may provide better error handling but also requires higher overheads.

## Application

The initial development of Bluetooth was intended to be a wireless means of communication between computer peripherals; keyboards, mouse, printers. Beyond this Bluetooth generally attempted to replace communication cables which were used for short range communications. Its low power usage however, made it ideal for handheld devices to adopt and today most handhelds (cell phones, PDA, notebooks, net-books) all implement Bluetooth chips as means to interconnect devices and exchange and transfer data files (business cards, music, pictures, PDF's, and other documents).

However today Bluetooth technology is used in a very wide spectrum of applications, from wireless gaming controllers (i.e. the 6 axis controller on the PS3), until creative "wacky" applications such as a smart hip, (use of Bluetooth to monitor joint implants, and ensure accuracy of surgery).

Considering the user, a basic user would use one implementation of a Bluetooth device. In essence it could be as simple as using a peripheral such as a wireless joystick, keyboard, mouse or headset; the user doesn't have to be aware of the technology being used (Bluetooth). On the other hand, if used for the exchange of data between devices, then the interface of the particular device will determine how simple/difficult it is to perform the specified tasks, such as sending pictures from a cell phone to a printer or a computer. The cases differ but Bluetooth aims to avoid complexities by acting as if the devices communicating are physically connected by a wire, and thus the users only task is to establish a connection (pairing).



## Usage & Costs

Bluetooth is very widely used in Thailand as similarly to around the world, its more or less a de facto standard to integrate Bluetooth chips into handheld devices. Bluetooth although originally developed by one corporation its large group of owners (Ericson, Toshiba, Intel, Microsoft . . .) implements Bluetooth technology within their own devices. In addition, the technology leaves room to be implemented in a very wide range of applications, creating a variety of opportunities for new and emerging markets.

Finally as Bluetooth uses low powered, low cost transceiver microchips, manufacturing cost of Bluetooth embedded devices are relatively low; each chip is estimated to cost about US\$ 4 to manufacture, which may be another reason why it is used so widely.

## Conclusion

Bluetooth chips are inexpensive to produce, and are supported by a large range of well known manufacturers. They provide a platform for hand held devices to inter communicate and can have countless possible applications. Bluetooth transmits over an unlicensed band, meaning there are no transmission costs, and uses a relatively low transmission power, in addition it incorporates FHSS providing better security and lower interference. Finally, Bluetooth has a decent Data rate of up to 3 Mb/s. All these reasons combined may briefly outline why Bluetooth is a low cost, low range, yet extremely successful means of wireless communication technology in modern day.

## 3.0 - Wi-Fi (Wireless Lan)

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## Introduction

Wi-Fi is most commonly used to intercommunicate within Wireless Local Area networks WLAN; even though it maybe substantially less effecient than a wired connection it gives its users the choice of mobility. Wi-Fi devices usually consist of an access point, and a Wi-Fi enabled device where all communications must go through the accesspoint.

## Wi-Fi Protocols

Wi-Fi uses the IEEE 802.11 standards defining the protocols, actually many different versions of a similar protocol was launched this report discusses 4 of the most widely used ones (802.11a/b/g/n), and more specifically concentrate on the architecture of the latest protocol (802.11n).

- 802.11 protocol  
defined 3 different technologies for the physical layer
  - diffuse Infrared
  - FHSS (Frequency hopping through Spread Spectrum)
  - DSSS (Direct Sequence Spred spectrum)Transmit over 2.4GHz ISM band
- 802.11a- same as the original specifications with the acception of OSDM (Orthogonal Frequency Division Multiplexing) this is a method where data is divided into multiple segments and than transmitted simultaneously in parrallel each using a different frequency; in theory castly increasing the data rate. Transmission over a 5GHz band
- 802.11b - is in general an extension of the original design, but able to provide a higher data rate.
- 802.11g - this standard tried to achieve the goods from both a/b protocols. 802.11a operating in a larger frequency band was more suceptible to absorption by barriers reducing the maximum distance it could travel, where as 802.11b was operating in a channel where it could cover a larger distance but experience more interference from other devices. So 802.11g, used the 2.4Ghz Band while utilizing OSDM, achieving aballance between high data rate and distance
- 802.11n - introduces Multi-input-multi-output transmitters (MIMO) its simply the use of multiple antennas to enhance OSDM and improve communications

## Data Transmission & Transmission Media:

Standard Specification	Frequency (GHz)	Bandwidth (MHz)	Modulation	Data Rate (Mbps)*	Range (m) (Indoor/Outdoor)	Transmit power	Recieve Sensitivity	Antenna
<b>802.11 a</b>	5	20	BPSK QPSK 16 - QAM 64 - QAM	54 Mbps	35/120	17 dBm	-73 dBm	Internal, External
<b>802.11 b</b>	2.4	20	CCK	11Mbps	38/140	23 dBm	-85 dBm	
<b>802.11 g</b>	2.4	20	OFDM CCK DBPSK DQPSK	54 Mbps	38/140	20 dBm	-74 dBm	
<b>802.11 n</b>	5 / 2.4	20/40	BPSK QPSK 16 - QAM 64 - QAM	600 Mbps	70/250	17 dBm	-73/-72 dBm	

\*Maximum Data rate

\* The receive sensitivity is according to the maximum data rate

## Modulation Techniques

Binary Phase Shift keying (BPSK)

Differential Binary Phase Shift Keying (DBPSK):

A variant of Binary phase shift keying.

16 - Quadrature Amplitude Modulation (16 – QAM):

Is a type of quadrature amplitude modulation that combines of 4 phases with 4 different amplitudes.

64 – Quadrature Amplitude Modulation (64 – QAM):

Is a typed of quadrature amplitude modulation.

Complimentary Code Keying (CCK):

In complimentary code keying there are codes used to encode a signal. One code word is 6 bits and there a total of 64 codes in total.

Differential Quadrature Shift Keying (DQSK):

The differential quadrature shift keying is a variant of quadrature shift keying.

Orthogonal frequency-division multiplexing (OFDM)

## Error Handling

Similar to the previous technologies discussed, Wi-Fi implement FEC, but in terms of Wi-Fi to suitably use FEC as a viable error detection and correction method it must use significantly large codewords. These codewords sometime may even be upto twice the size of the original packet or greater. Thus Wi-Fi can use FEC scheme to correct errors more effectively but this can greatly increase overheads reducing the throughput. For instance even though the data rate maybe 54 Mb/s considering FEC codewords the throughput can be as low as 15Mb/s, which is a very large trade off.

## Applications

<b>Standard</b>	<b>802.11n</b>
<b>Scenarios</b>	Covering a House, or an Internet café with WIFI.
<b>User</b>	A User connects in the house to the wireless Lan on order to connect through the router to the internet.
<b>Devices Required</b>	A Sender, a so called Access point And a Receiver, a Wireless Lan USB device.

## Usage

Wireless Lan, WIFI is nowadays used all over the world. Especially for home users it is a cheap and easy option to connect their devices throughout the house without rewiring.

Since the new standard with an amazing transfer rate of 300 MBit/s is ensuring a fast and reliable data exchange, WIFI turned out to be an option even for high data rate demanding facilities like offices and Public places.

## Costs

The initial cost are very cheap. An Access point and a receive device can be together received for less than 1000 THB. Since one Repeater is capable of handling more than one communication device, the expanding cost are even lower. Running costs are besides electricity for powering the devices zero.

## 4.0 - WiMAX (Worldwide Interopability for Microwave Access)

## Introduction:

WiMAX Technology is a new Wireless technology, based on WIFI Networks. The Standard IEEE 802.16 ( BWA, Broadband Wireless Access) describes the wireless Broadband technique for a Wireless Metropolitan Area Network ( MAN), which was invented with the IEEE 802.11 ( Wireless LAN) Standard similar. In year 2001 the standard 802.16 was defined. 2004 the standard 802.16d for fixed access and 2005 the standard 802.16e for mobile stations was defined. WiMAX is supposed to be an alternative to Landline DSL, especially in rural areas without fast Internet Access.

## Protocol Architecture:

The WiMAX standard IEEE 802.16 defines only the first and the second layer of the OSI model. It is the air interface between the Subscriber Transceiver Station and the Base Transceiver Station

- OSI Physical Layer
  - Transmission and coding of the signal
  - Preamble generation/removal
- OSI Data Link Layer
  - Assemble and disassemble frames, and perform address recognition and error detection
  - Provide access to the wireless transmission medium

## Signal Encoding Technology:

To provide a better signal quality the following techniques are used:

- Orthogonal Frequency Division Multiplexed Access ( OFDMA)
  - The Physical layer uses the OFDMA technique. With this it has the ability to use the Channel separation of the whole Frequency band more effectively. By using Scalable OFDMA each channel is able to use its own modulation technique ( QPSK, 16QAM, 64QAM) based on its transmission quality.
- MIMO
- TDD ( Time-Division Duplexing)
- FDD(Frequency division Duplexing)
  - The innovation in WiMAX compare to WIFI 802.11 is, that it can now transmit and receive on different frequencies at different times.
- CDMA( Code Division Multiple Access)
  - Base stations can adjust their power based on the distance of the clients, to reduce interference

## Data Transmission

Type	IEEE 802.16	IEEE 802.16d-2004	IEEE 802.16e-2005 Mobile
<b>Standardized</b>	2001	2004	2005
<b>Spectrum</b>	10 – 66 GHz	2 – 11 GHz	0.7 – 6 GHz
<b>Bandwidth</b>	20,25 and 28 GHz	Scale able from 1.5 to 20 MHz	5/7/8.75/10/20 MHz
<b>Data Rates</b>	Up to 134 Mbits 28 MHz channel	Up to 75 Mbits 20 MHz channel	Up to 15 Mbits 5 MHz channel
<b>Max. range</b>	Up to 75 km	Up to 5 km with indoor antenna Up to 15 km with outdoor antenna Max 50 km	Up to 5 km Typical 1.5 km
<b>Modulation</b>	QPSK, 16QAM, 64 QAM	OFDM256, OFDMA, 64QAM, 16QAM, QPSK,BPSK	OFDM256,OFDMA,64QAM 16QAM,QPSK,BPSK
<b>Receiver</b>	Fixed	Fixed	Mobile

## Used frequencies

Region	Band
Europe	3.5 GHz / 5.8 GHz
Asia Pacific	2.3 GHz / 2.8 GHz/ 3.3 GHz/ 3.5 GHz/ 5.8 GHz

## Transmission Media

Transmission media	IEEE 802.16 d and e
<b>Transmit power</b>	In Germany the max sending power is regulated to 3.2 W
<b>Receive thresholds</b>	136.4 dB
<b>Antennas</b>	Smart Antenna Techniques with OFDMA On vector flat sub carriers
<b>Distance</b>	Up to 75 km



## Errors

Hybrid Auto Repeat Request ( HARQ) is used by mobile WiMAX. It is using N Channel "Stop and Wait" protocol to ensure fast response errors.

## Applications

The Standard is chosen upon the users requirements to ensure the highest possible performance.

Standard	802.16d Fixed	802.11e Mobile
<b>Scenarios</b>	A cell based coverage for rural regions, with fixed outdoor antennas.	A cell based coverage for Metropolitan areas MAN.
<b>Used by User</b>	A typical business without DSL internet connection could connect multiple users through one Outdoor antenna in rural areas.	A User with a WiMAX Laptop card could connect to the network in the city.
<b>Devices Required</b>	Network infrastructure. Sending Bases or Cell Base. And a Fixed mounted Outdoor antenna.	A Cell based infrastructure and a USB WiMAX stick.

## Usage

WiMAX actually has a test site in Thailand's north, but it is not open for consumers yet. The actual standards are still not 100% compatible to each other, which makes it hard for the network operator to choose the correct Hardware and implement the technique on the market.

Since Cisco stopped investing in WiMAX and therefore researches on LTE ( Long Term evolution), most Manufacture and Network companies hesitated to invest in a WiMAX Network structure and wait for the new 3G Standard, 3G+ or LTE called, which can be used with less investments, since the current 3G Network structure is already available.

This does not imply to Thailand though, since it doesn't even have a complete 3G coverage. For Most European countries this is the main factor why the rollout of this technology is still delayed or even suspended in some regions since 3G is already available.

## Cost

The Cost are similar than building up any new network coverage. GSM for example. That means the cost for building up a whole covered network for the Network Operator are huge. Because WiMAX has far different data rates and ranges, the existing 3G bases cant be used. The cost for the user are comparably small, since the only need hardware is either a USB stick, or a outdoor antenna. The associated costs are like every other mobile network, it needs maintenance.

# Wireless Technology Comparison

Table - Basic **Wireless Technology Comparison**

	<b>Zigbee</b>	<b>Bluetooth</b>	<b>Wi-Fi</b>	<b>WiMAX</b>
<b>Usage</b>	Sensors & Controls, Interdevice Communication (WPAN)	Short Range communication, Cable replacement	Short Distance communication	Long Distance communication
<b>Frequency</b>	868 / 915 / 2450 MHz	2.4 GHz	2.4 / 5 GHz	10 - 66 GHz
<b>Max Transmit Power</b>	2.8 mW	0.25 -100 mW	200 mW	20 W
<b>Max Data Rate</b>	250 kbps	3 Mb/s	600 Mbits	134 Mbits
<b>Max Range</b>	90 m (indoor)	1 -100 m	300 m	75 km

The Wireless transmission technologies in outlines above (discussed in this report) are difficult to compare and judge as they were each developed to serve a different purpose. But some of the general Discussions are found below.

If we begin by comparing Bluetooth to Zigbee, they are both relatively low powered devices, and can cover approximately an equivalent range (100m). But they have very different Data Rates; Zigbee which is normally used for sensors and control devices only need to transmit small amounts of specific sensory data where as Bluetooth may perform transfers of larger files such as voice. Bluetooth could perform the same task as a Zigbee device, however the major advantage of Zigbee being that its low power consumption allows it to be self sustainable up to 2 years without a battery re-charge or change. Hence making each technology appropriate for its purpose.

If we consider Wi-Fi against WiMAX; The use of Wi-Fi is limited to domestic use, although Wi-Fi can cover a range of a 100 m's it can only interconnect devices within this range. WiMAX however can broadcast a distance of 75Km's which makes it ideal for communicating with devices in rural areas, which Wi-Fi cannot achieve. In addition, the cost of setting up wired communication networks from urban to rural areas is far more costly then setting up a single WiMAX base station. It's one disadvantage however is that each WiMAX base station must have a distance of at least 28 m's from any of its communicating devices which means that it's not a good solution for domestic use unlike Wi-Fi.

So it can be concluded that each technology was designed to perform a designated role and each technology does it well, with little flexibility, where one cannot be compensated by another, and therefore, comparisons are hard to make. Each technology also implements different Protocols, Error Handling techniques, and signal encoding schemes, but it's not obvious that any one method is better than the other; they each have their trade offs (pros / cons) and requirements to perform their specific tasks.



# Bibliography

## Bluetooth Bibliography

(n.d.).

*Bluetooth Costs* . (2010). Retrieved Sep 2010, from BlueTomorrow:  
<http://www.bluetomorrow.com/about-bluetooth-technology/general-bluetooth-information/bluetooth-costs.html>

Architect), S. R. (2000). *Bluetooth*. Retrieved Sep 2010, from Infrastructure:  
[http://www.omimo.be/magazine/00q4/2000q4\\_p028.pdf](http://www.omimo.be/magazine/00q4/2000q4_p028.pdf)

*Bluetooth*. (2010, Sep 4). Retrieved Sep 2010, from Wikipedia:  
[http://en.wikipedia.org/wiki/Bluetooth#LMP\\_.28Link\\_Management\\_Protocol.29](http://en.wikipedia.org/wiki/Bluetooth#LMP_.28Link_Management_Protocol.29)

*Bluetooth Protocol Architectures* . (n.d.). Retrieved Sep 2010, from Blue Tomorrow :  
<http://www.bluetomorrow.com/about-bluetooth-technology/how-bluetooth-works/bluetooth-protocol-architecture.html>

*Developing Bluetooth Technology Solutions*. (n.d.). Retrieved Sep 2010, from Bluetooth:  
<http://bluetooth.com/ENGLISH/TECHNOLOGY/Pages/default.aspx>

*Verifying Bluetooth™ Baseband Signals*. (2004, Sep 9). Retrieved Sep 2010, from Agilent Direct:  
<http://cp.literature.agilent.com/litweb/pdf/5988-2181EN.pdf>

## WiMAX Bibliography

(n.d.). Retrieved from [http://www.tutorialspoint.com/wimax/wimax\\_network\\_model.htm](http://www.tutorialspoint.com/wimax/wimax_network_model.htm)

(n.d.). Retrieved from <http://www.wimax.com/wimax/>

VA. (n.d.). *Elektronik Kompendium*. Retrieved from <http://www.elektronik-kompendium.de/sites/net/0904211.htm>

## Zigbee Bibliography

(2010, September 1). Retrieved from Wikipedia: <http://en.wikipedia.org/wiki/ZigBee>

IEEE Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Network (WPANs) . (2006, September 8).

Kenney, P. (2003, October 2). ZigBee Technology: Wireless Control that Simply Works.

McGuigan, B. (2010, August 9). Retrieved from Wise geek: <http://www.wisegeek.com/what-is-zigbee.htm>

*Products*. (n.d.). Retrieved from Digi Making Wireless M2M Easy:  
<http://www.digi.com/products/wireless/zigbee-mesh/>

*Wikipedia*. (2010, September 1 ). Retrieved from <http://en.wikipedia.org/wiki/ZigBee>

ZigBee Specification. (2006, December 1).

*ZigBee Topologies*. (n.d.). Retrieved from Jennic:  
<http://www.jennic.com/elearning/zigbee/files/html/module2/module2-1.htm>

## Wi-Fi Bibliography

(n.d.).

*802.11 Protocol Stack and Physical Layer* . (2009, Mar 29). Retrieved Sep 2010, from Scribd:  
<http://www.scribd.com/doc/13628928/80211-Protocol-Stack-and-Physical-Layer>

*Data Sheet* . (n.d.). Retrieved Sep 2010, from Cisco:  
[http://www.cisco.com/en/US/prod/collateral/wireless/ps5678/ps6973/ps8382/product\\_data\\_sheet0900aecd806b7c5c.html](http://www.cisco.com/en/US/prod/collateral/wireless/ps5678/ps6973/ps8382/product_data_sheet0900aecd806b7c5c.html)

*Published WiFi Specifications*. (2010). Retrieved Sep 2010, from WiFi Alliance: [https://www.wi-fi.org/knowledge\\_center\\_overview.php?type=4](https://www.wi-fi.org/knowledge_center_overview.php?type=4)

Sobek, R. P. (2002). *Wireless Fidelity (Wi-Fi) - Specifications*. Retrieved Sep 2010, from Wi-Fi (Irit):  
<http://www.irit.fr/~Ralph.Sobek/wifi/>

*Wi-Fi*. (2010, Sep 7). Retrieved Sep 2010, from Wikipedia:  
[http://en.wikipedia.org/wiki/Wifi#Direct\\_computer-to-computer\\_communications](http://en.wikipedia.org/wiki/Wifi#Direct_computer-to-computer_communications)