OULU UNIVERSITY OF
APPLIED SCIENCES

Anayo Joakim Osimeleze

ubiPILL MOBILE CLIENT FOR HELPING NURSES TO REMOTELY MONITOR PATIENT'S MEDICINE TAKING AND SET ALARM TIMES

ubiPILL MOBILE CLIENT FOR HELPING NURSES TO REMOTELY MONITOR PATIENT'S MEDICINE TAKING AND SET ALARM TIMES

Anayo Joakim Osimeleze

Bachelor's thesis

Spring 2013

Degree Programme in Information Technology

Oulu University of Applied Sciences

PREFACE

This Bachelor's thesis was done at Oulu University of Applied Sciences School of Engineering, Raahe campus.

It is a thing of joy that I attended Oulu University of Applied Sciences, I am privileged to be part of this history and it is something that will always remain with me.

I would like to thank Juhä Räty, my supervisor and Jori Karppinen for their wonderful guidance and encouragements which helped me in completing my thesis, without your guidance it would have been difficult for me to have completed it. Words are not enough to express my gratitude towards you.

I would also give my gratitude to the entire staff of Oulu University of Applied Sciences in Raahe for the opportunity given to foreign students to study in Raahe, and also for their immense effort in making sure that the students achieve their aim by given them the right tools, time and offering the right environment.

Separately, I would like to thank Janne Räihä, Elina Keskitalo and Teija Harju for the great work they are doing in their different departments.

Finally, I would like to thank my family and friends who were behind me and supported me throughout my time in school.

Raahe, 20 May

Osimele Anayo Joakim

IIVISTELMÄ

Oulun seudun ammattikorkeakoulu

Koulutusohjelma: Tietotekniikka

Kirjoittaja: Anayo Joakim Osimeleze

Opinnäytetyön otsikko: ubiPILL Mobile client for helping nurses to remotely patient's medicine taking and set alarm times
Ohjaaja: Juha Raty

Termi ja valmistumisvuosi: Kevät, 2013 Sivumäärä: 54

Tämä insinöörityö on tutkimus Bluetooth-teknologian viimeisimmästä versiosta, Bluetooth v. 4.0. Sitä olisi tarkoitus käyttää ubiPILL-projektissa standarditiedonsiirtomenetelmänä sekä potilasdatan keräämisessä että sen siirtämisessä keskusyksikköön.Bluetooth 4.0 on täysin erilainen kuin aikaisempi klassinen Bluetooth-tekniikka, siinä on kolme eri tekniikkaa sidottu yhteen ja sitä voidaan lisäksi käyttää myös omana tekniikkanaan, ns. "stand alone" -tyylisesti.

Tämä tutkimus perustuu siihen kuinka ikääntyvien ja esim. muistikatkojen vaivaamien sairaiden kohdalla tätä tekniikkaa voitaisiin soveltaa potilasetätietojen keräämisessä.

Terveydenhuollon apuvälineiden kehityksestä vastuussa olevat alan johtavat yritykset ovat valinneet Bluetooth Low Energy -tekniikan standardikseen sen erittäin pienen tehonkulutuksen ja edullisuuden takia. Bluetooth on tämän hetken johtavin langattomien tekniikoiden sovellutus ja tässä päättötyössä keskitytään selvittelemään sen uusimman version soveltuvuutta lääketieteellisissä sovellutuksissa.

Avainsanat: Bluetooth Low Energy, ubiPILL, langaton valvonta, langaton terveydenhoito, Bluetooth 4.0

ABSTRACT

Oulu University of Applied Sciences

Degree programme in Information Technology

Author: Anayo Joakim Osimeleze

Title: ubiPILL Mobile Client for Helping Nurses to Remotely Monitor Patient's Medicine Taking and Set Alarm Times

Supervisor: Juhä Räty

Term and year of completion: Spring 2013 Number of pages 54

This Bachelor's thesis was a research on the recent Bluetooth technology feature incorporated into the Classic Bluetooth; Low Energy. The technology was intended to be used in hospitals for helping nurses to remotely monitor aging and sick people with memory lapses. This thesis was commissioned by ubiHOME lab, a unit in Oulu University of Applied Sciences.

I studied this technology six hours every day during the evenings and mid nights by reading and by watching YouTube videos. Sixty percent of the information is from Bluetooth website and Wikipedia.

Bluetooth Low Energy is the number one wireless technology for Telehealth application development because of its ultra-low power, low cost and multi-vendor interoperability. I want to further develop this thesis by writing a Telehealth application that will be used to monitor an aging person remotely, using Java Script and PHP technologies.

Keywords: Bluetooth Low Energy, ubiPILL, Remote monitoring, Telehealth, Bluetooth v4.

TABLE OF CONTENTS

1 INTRODUCTION 5

2. BLUETOOTH OVERVIEW 6

2.1 What is Bluetooth Technology? 6

2.2 The basis of Bluetooth 6

2.3 Range 7

2.4 How Bluetooth works 7

2.5 Date of Invention 9

2.6 Name of Origin 9

2.7 Different versions of Bluetooth 10

3. CORE ARCHITECTURE 13

3.1 Core System Architecture 13

3.2 Profiles Overview 13

3.3 Security 17

3.4 Core System Architecture 18

3.4.1 Controller 19

3.4.2 L2CAP Layer 21

3.4.3 Host to Controller Interface (HCI) 22

4. BLUETOOTH LOW ENERGY 23

4.1 Bluetooth 4.0 Technical Information 24

4.1.1 High Speed 25

4.1.2 Enhanced Data Rate 27

4.1.3 Frequency Hopping 28

4.1.4 Security 32

4.1.4.1 Association Models 32

4.1.4.2 Key Generation 33

4.1.4.3 Encryption in Bluetooth Low Energy 34
4.1.4.4 Data Security 34
4.1.4.5 Privacy Feature 34
4.1.5 Usability 35
4.1.5.1 Sports and Fitness 35
4.1.5.2 Plant Monitoring 38
4.1.5.3 Health 39
5. BLUETOOTH LOW ENERGY VS CLASSIC BLUETOOTH 42
5.1 Single-mode and Dual-mode 42
5.2 Difference in Profiles 42
5.3 Master and Slave connection 43
5.4 Low Power 43
5.5 Common Features 43
5.6 Limitations 43
6. BLUETOOTH LOW ENERGY FOR ubiHOME PROJECT 46
6.1 Bluetooth Low Energy versus Zigbee 47
7. CONCLUSIONS 51
REFERENCES

1 INTRODUCTION

This thesis is about Bluetooth Low Energy wireless technology as a standard for building medical applications for remote monitoring of aging and sick people. Before the emergence of this technology it was very expensive to monitor people with memory lapses (old and sick people) remotely. The emergence of Bluetooth version 4.0 which has the Low Energy feature has helped to reduce cost and makes it easier for doctors, nurses and caretakers to monitor people through the pairing of sensors with mobile phones.

This book is for anyone who is interested in knowing about Bluetooth Low Energy technology, most significantly for application developers and software managers who are interested in building telehealth applications for remote monitoring, or for security and sports and fitness, using Bluetooth Low Energy technology.

2 BLUETOOTH OVERVIEW

Previously before the advent of wireless technology, devices were connected to each other using cables but in today's world wireless technology is taking over in residential homes and in offices. Bluetooth is one of those technologies used in communication between devices.

2.1 What is Bluetooth technology?

Bluetooth is a 2.4GHz wireless radio frequency technology designed for data transmission over short distances. The devices working with Bluetooth technology within a specific range are interconnected, creating a personal area network (Wikipedia, Bluetooth, date of retrieval 4.4.2013).

2.2 The basis of Bluetooth

A device is said to be Bluetooth enabled if it has Bluetooth technology in it. Two Bluetooth devices can communicate with each other and the term for this is called pairing. Bluetooth is secured and can be found in many products ranging from mobile phones, cars, medical devices, watches, computers and home entertainment products. Below are some examples of devices that use Bluetooth technology.

FIGURE 1. Examples of devices that use Bluetooth technology

It was originally created to replace RS-232 cable connections (Wikipedia, Bluetooth, date of retrieval 4.4.2013). Bluetooth was designed to consume very small amount of power. When data is not transferring it powers off/down the radio links making the links safe and also helps in power optimization. This makes the battery last for a long time.

2.3 Range

The minimum range as mandated by the SIG group is 10m or 30 feet. The range can be any range depending on the application or use cases. The application or use cases call for the class of radio to be used (Bluetooth SIG, Bluetooth Basics, date of retrieval 07.04.2013). There are different classes of radios in communication:

- **Class 3 radios**

  The range of this radio is up to 1 meters = 3 ft.

- **Class 2 radios**

  The range of this radio is 10 meters = 33 ft. This is the radio commonly used in mobiles. It uses 2.5 mW of power.

- **Class 1 radios**

  The range of this radio is 100 meters = 300 ft.

2.4 How Bluetooth works

Data transmission is achieved through a short-wavelength radio transmission from 2400–2480 MHz in the ISM band. During the data transmission, data is divided into packets and each one of these packets is transmitted along 79 channels starting from 2402 MHz and continuing up to 2480 MHz in 1 MHz steps, performing 1600 hops every second with Adaptive Frequency-Hopping

enabled (AFH). Each of the channel signals data at 1Mb/s .This method is called Frequency-hopping Spread Spectrum. The carrier was initially modulated using only Gaussian Frequency Shift Keying (GFSK) in the first Bluetooth version, but due to the requirement of higher data rates, π/4 DQPSK and 8DPSK were introduced in Bluetooth 2. π/4 DQPSK and 8DPSK are called EDR(enhanced data rate) with data rate of 2Mbit/s and 3Mbit/s (Wikipedia Bluetooth, date of retrieval 4.4.2013).

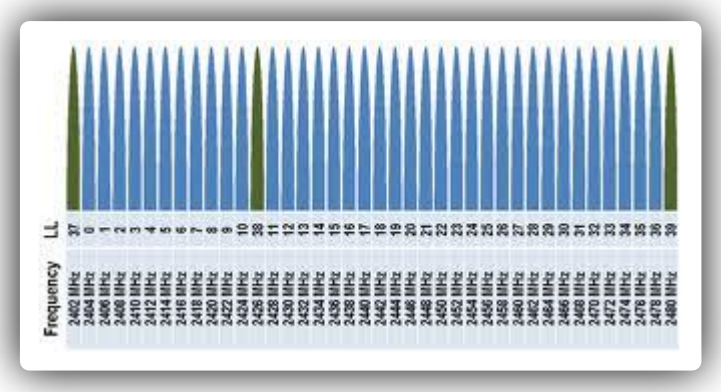

FIGURE 2. Bluetooth Low Energy Radio Frequency Channels (Rolf Nilsson & Bill Saltztein 2011, date of retrieval 4.4.2013)

Bluetooth is designed in a master-slave structure. In Bluetooth communication, all devices in a piconet share the master's cloak. The master can communicate with up to 7 slaves in a piconet, and the mode of data transmission is defined by the master's cloak. In a single slot packet transmission, data is transmitted in even slots by the master and is received in odd slots. Twice the master's cloak tick which is 625µs makes up a slot, the master ticks in every 312.5µs. The slave(s) in the other way round receives packets in even slots and transmit in odd slots (Wikipedia, Bluetooth, 4.4.2013).

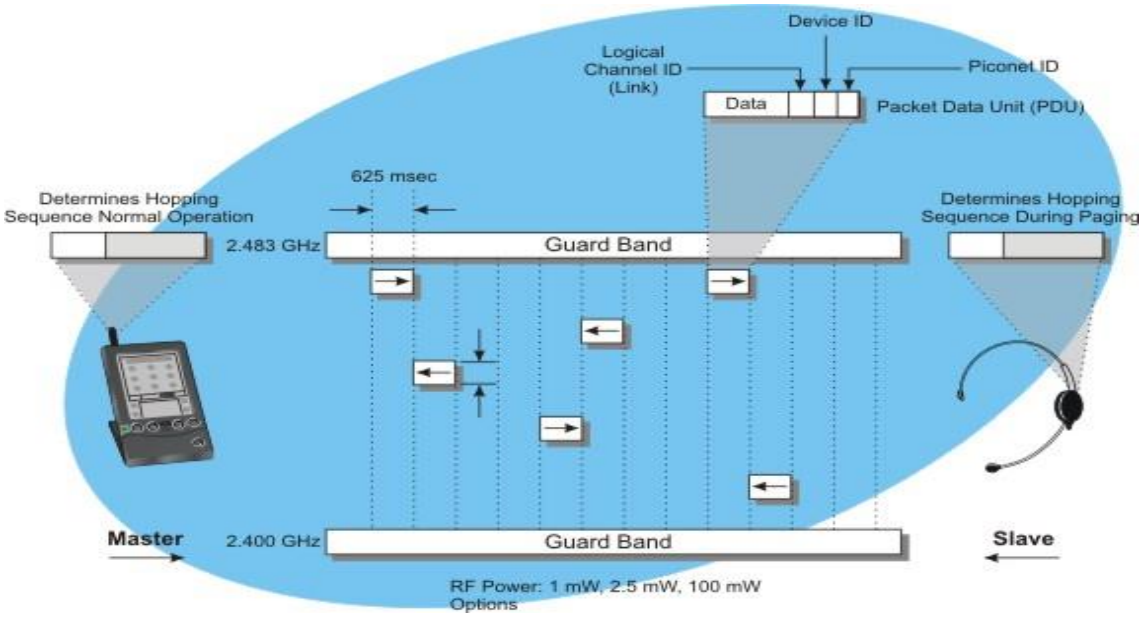

FIGURE 3. Shows how Bluetooth works (Lawrence Harte 2008, date of retrieval 4.4.2013)

The above diagram shows a packet transmission in Bluetooth RF. As you can see from the diagram, the master's cloak defines the packet transmission in a Bluetooth Radio frequency. The master transmits in even slots and receives in odd slots, while the slave transmits in odd slots and receives in even slots. It also shows that a packet contains a piconet id, a device id and a logical channel id, and also that frequency range of Bluetooth system.

2.5 Date of Invention

Ericsson invented Bluetooth in 1994 and in 1998 the SIG (Special Interest Group) group was formed. This group is made up of many companies across the world. They oversee the development of Bluetooth technology.

2.6 Name Origination

The name Bluetooth originated from a Danish king Herald Blåtand or Harold Bluetooth in English. In the 10th century King Harald unified groups of warring people in Denmark, Norway and Sweden. The SIG group adopted that name because Bluetooth Technology brings together different products making them

to communicate just as King Herald Blätand did in his days. (Bluetooth Wikipedia, Bluetooth, 4.4.2013)

2.7 Different versions of Bluetooth

There are different versions of Bluetooth since the inception/arrival of Bluetooth wireless technology, all these versions are downward compactible. (Wikipedia, Bluetooth, date of retrieval 4.4.2013).

- **Bluetooth 1.0 and 1.0B**

  Bluetooth version 1.0 and 1.0B had a huge problem of interoperability within different devices from different manufacturers. The implementation of BD_ADDR (Bluetooth device address) in transmission when connecting made it difficult for other programs which were at first thought to be used in Bluetooth.

- **Bluetooth 1.1**

  Bluetooth version 1.1 was an improved version of 1.0B, few supports were added e.g. RSSI (Received Signal Strength Indicator) and channels encryption.

- **Bluetooth 1.2**

  Bluetooth version 1.2 was improved with the addition of AFH (Adaptive Frequency Hopping Spread Spectrum) which helps against interference in the RF. Other enhancement include, the transmission speed, extended synchronous connections (eSCO) which help to retransmit corrupted da-da, faster connection and service discovery and HCI that supports UART with three wire.

- **Bluetooth 2.0**

  Bluetooth version 2 came with an enhancement which improves the rate of data transfer in Bluetooth technology. EDR (Enhance Data Rate) was added for faster data transfer and the speed of data transfer between devices is 3Mbit/s. This is achieved by different radio technologies merging together when transmitting data from one device to the other. EDR uses GFSK (Gaussian Frequency Shift keying) modulation in combination with (PSK) Phase Shift Keying Modulation while BR (Basic Rate) uses GFSK only.

- **Bluetooth 2.1**

  Bluetooth 2.1 enhancement improved the filtering of devices during connection by providing more information of the device. The information includes the device name which by default is the name of the manufacturer, services which the devices are supporting, and pairing information.

  Low power consumption by using a sniff-sub rating technology also enhances this version of Bluetooth as devices like, keyboards, mouse, headsets and sensors benefit greatly from it. It increases the life span of coin-cell batteries by making devices negotiate the length of time they have to wait before sending keep-alive messages between them. (Wikipedia, Bluetooth, 6.4.2013).

  The stronger encryption for connections stays up for many hours or day. The encryption key keeps refreshing every time which makes it difficult to de-code and track.

- **Bluetooth 3.0**

  Bluetooth version 3.0 enables Bluetooth to transfer data at a very high speed of up to 480 Mbit/s while also supporting the ultra-low power con-

sumption of Bluetooth. It uses the high speed 802.11 similar to Wi-Fi to transmit data. (Wikipedia, Bluetooth, 6.4.2013).

- **Bluetooth 4.0**

  Bluetooth version 4.0 is the latest version of Bluetooth technology, it has the Low Energy feature in it and it is designed for devices like watches, sensors, toys etc. It is of great benefit to hospitals, because it helps in reducing costs and increasing effective monitoring of aging and sick people remotely. It will also benefit sports men and women for keeping fit by measuring of heartbeat while exercising.

  When you are in a meeting and your phone is inside your bag or pocket and in a silent mode, paired with a Bluetooth Low Energy enabled watch, then if a call comes in, it will display in your watch and you can choose to answer the call or reject the call. If you have left your phone behind, you will get a reminding message or an alert from your watch telling you that your phone is left behind. It can also show you the location of the phone if you do not remember where it was kept. (Wikipedia, Bluetooth, 7.4.2013).

3 CORE ARCHITECTURE

In the Bluetooth core specification, the sub systems of the Bluetooth architecture are able to operate with each other by the definition of an interface between the controller and the upper layers. Also, each part/layer in a system is also able to communicate with another part/layer by a protocol definition of the message exchanged between them.

3.1 Core system protocols and signaling

There are three different types of services in the Bluetooth core system, the first two belongs to the U-plane while the last one (data service) belongs to the C-plane. (Bluetooth developer portal Core System Architecture 2013, date of retrieval 15.3. 2013)

- **Device control services**

  This service takes care of the mode and the behavior of Bluetooth device.

- **Transport control services**

  This service is responsible for creation, managing and disconnection of links and channels.

- **Data services**

  This service is used to send data out for transmission.

3.2 Profiles Overview

Bluetooth profiles are applications that are developed by application developers, used in communication between Bluetooth enabled devices. (Bluetooth SIG, profiles overview, 10.4.2013).
A Bluetooth profile specification must contain the following topics:

- Dependencies on other formats
- Suggested user interface formats
- Specific parts of the Bluetooth protocol stack used by the profile.

There are a wide range of Bluetooth profiles which I am going to name a few. (Bluetooth SIG, profiles overview, 10.4.2013).

- **HCRP (Hard copy replacement profile)**
  This profile is responsible for the connection of a Bluetooth enabled printer and Bluetooth enabled device wirelessly. (Bluetooth SIG, profiles overview, 10.4.2013)

- **SIM access Profile**
  This profile allows a mobile phone that is Bluetooth enabled with a SIM card to connect to a device that has the capability to receive and transmit data but has no SIM card, making the two devices to share one SIM card. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Synchronization Profile**
  This profile is used with Generic Object Profile (used in object transfer) to synchronize PIM items between Bluetooth enabled devices. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Video distribution Profile**
  It is used for streaming of video. (Bluetooth SIG, profiles overview, 10.4.2013)

- **SDAP(Service Discovery Application Profile)**

With this profile an application can discover a service using SDP. (Bluetooth SIG, profiles overview, 10.4.2013)

- **SPP(Serial Port Profile)**
  This is virtual substitute for RS-232 cable connecting Bluetooth enabled devices. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Audio/Video Remote Control Profile**
  This profile communicates with a remote controller to provide access to TVs and other video and audio devices. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Cordless Telephony Profile**
  This profile supports the connection of a mobile device without a cord to connect to a landline via Bluetooth using a Bluetooth CTP gateway. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Device Id Profile**
  This profile is very important when downloading drivers, it helps you to download the appropriate diver for that particular device. Also it helps PCs to identify the particular device they are connecting with, requesting the manufacturer's information of the device. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Dial Up Networking Profile**
  This profile enables a device have access to the Internet via a computer or any dial-up service. An example is connecting to a modem with your mobile device or to your computer in order to use the computer's Internet. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Hands-free profile (HFP)**
  This profile is used in a car to communicate with a mobile phone through hands free device technology. The technology inbuilt in the car allows

you to make or receive a call without holding the mobile phone in your hand. The picture below is an illustration of how a hands-free device or headset in connection with a mobile phone works.
HFP can also be found in devices like, GPS system, headsets, mobile phones etc. (Bluetooth SIG, profiles overview, 10.4.2013)

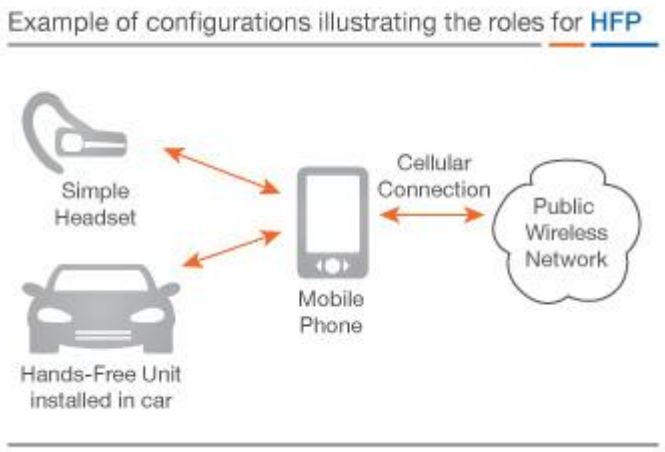

FIGURE 4. Example of how HFP works in devices. (Bluetooth SIG, Hands-free profile (HFP), 10.4.2013).

- **Health device profile (HDP)**
  This profile is used to transfer and receive medical data. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Headset profile (HSP)**
  The profile makes it possible for headsets to work with a mobile. With this profile you are able to listen to music with your headset connected to your mobile. (Bluetooth SIG, profiles overview, 10.4.2013)

- **LAN access profile (LAP)**
  LAP makes it possible for a Bluetooth enabled device to connect to LAN, WAN or the Internet through a device that is physically connected to that network. This profile has been replaced by Bluetooth with PAN. (Bluetooth SIG, profiles overview, 10.4.2013)

- **Generic object exchange profile (GOEP)**
  This profile is responsible for the provision of the requirement necessary for an OBEX support in Bluetooth devices. (Bluetooth SIG, profiles overview, 10.4.2013)

3.3 Security

The security in Bluetooth technology is very important because of eavesdropping and data corruption. Security mode is implemented by the manufacturers of Bluetooth products (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

There are four modes of security during access between devices. The four security levels are:

- **Mode 1**

  Security mode 1 is a non-secured security. (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

- **Mode 2**

  Security mode 2 is a service level enforced security. In this mode of security both devices establish a connection before the security protocol is initiated. (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

- **Mode 3**

  Security mode 3 is a link enforced security. It is the inverse of mode 2; the protocol is initiated before a connection is established. (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

- **Mode 4**

Security mode 4 is a link level enforced security. The difference between mode 3 and mode 4 is that in mode 4, the link is encrypted using an encryption key. (Bluetooth SIG, security, date of retrieval 3.4.2013).

There are two security levels in a device:

- **Trusted Device**

  In a trusted device a link key is stored after authentication in the database of the device. It means that it is paired with another device and marked as a trusted device. (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

- **Untrusted Device**

  At an untrusted device level the device is authenticated and then a link key stored but the device is not marked as trusted. (Cathal Mc Daid Feb 2001, Bluetooth Security Part-1, date of retrieval 3.4.2013).

  There are three security levels in devices (Bluetooth SIG, security, date of retrieval 3.4.2013).:

- Services that require authorization and authentication
- Service that require authentication only
- Services that are open to all devices

3.4 Core Architecture Blocks

The core architecture block consists of the Controller and the L2CAP layer. A Bluetooth protocol stack consists of a Baseband which is the hardware that makes the connectivity possible between devices wirelessly, RF for transmitting and receiving signals, a link controller unit, a link manager, a host controller interface (HCI), a logical link control and an adaptation

protocol(L2CAP) (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

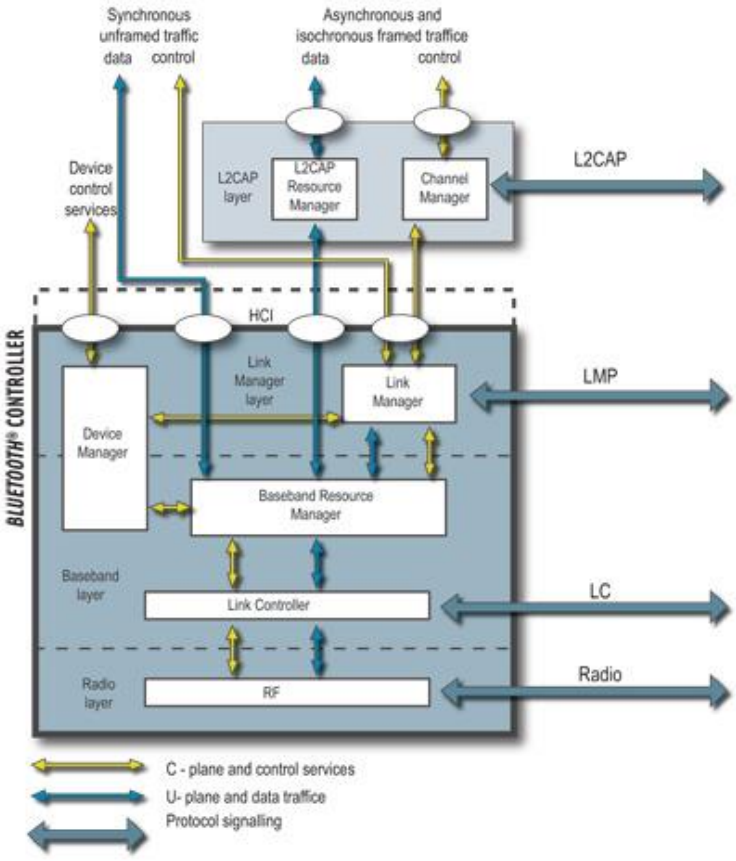

FIGURE 5. Core specification of Bluetooth (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

3.4.1 Controller

The Bluetooth controller comprises of four layers with three lower layers forming the controller; the link manager layer, the Baseband layer and the Radio layer. The four layers are the following layers. (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

- **Radio Frequency**

  The radio frequency is the lowest in the Bluetooth protocol stack. The Bluetooth RF transceiver allows a Bluetooth enabled device to transmit or receive data from another Bluetooth device wirelessly. The Bluetooth

channels and links are been handled by the baseband. *(*Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

- **Link controller**

The link controller and the Baseband manager are in the Baseband layer. The controller is the one that processes the data, and sends and receives data. It also authenticate and encapsulate data, knows when to send data and when not to send, knows the sending device in a piconet, determines the frequency carrier to use when sending and saves power when there is no transmission of data. (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

- **Baseband Resource manager**

Without the Baseband manager there would not be any access to the Bluetooth radio channels (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

. It has two main functions:

a) Scheduling time

There is a scheduler in the Baseband resource manager that grants time on the radio channels to devices that have contacted for access.

b) Negotiating an access contract

It negotiates an access contact with these devices. This means that it delivers the required service for the right application.

These two functions must take into account any behavior in a device that uses Bluetooth Radio; for transmission of data, inquiries, connectivity etc.

A link can be changed to a different channel if the physical channels are not time slot align. The Resource manager is responsible for rescheduling the link

to a new channel. This happens because of a page scanning, an incessant inquiry or an involvement of scatternet. (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

- **Device manager**

  The Device manager is responsible for the device discovery, the connectivity with devices that has Bluetooth technology, and the inquiry of a device with a Bluetooth technology within that particular vicinity or range. (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

- **Link manager**

  The link manager connects, terminates and manages a link between devices. (Bluetooth SIG, Core System Architecture, date of retrieval 27.3.2013)

3.4.2 L2CAP LAYER

The L2CAP is called the logical link control and adaptation protocol. It belongs to the Host system which comprises the service layers and the higher layers known as the Bluetooth Host. L2CAP is responsible for the transmission of packets from higher layers. These packets are transmitted or received through logical channels via HCL (HOST Controller Interface). The service discovery protocol (SDP) - The SDP is part of the L2CAP. As the name imply, it is used to identify the type of service or profile that a Bluetooth device supports and what Universal Unique Identity (UUID) it uses to connect with that specific service. (Bluetooth SIG, Core System Architecture, date of retrieval 1.4.2013)

- **Channel manager**

  The Channel manager creates a connection with a remote device using the L2CAP protocol in order to convey packets across to a remote device through L2CAP channels. It also manages the channels and disconnects the links when there is no communication between the entities. The channel manager communicates with the ACL link or link manager before a link creation and also configures the link to another for the rendering of an appropriate service required for the particular data been transported. (Bluetooth SIG, Core System Architecture, date of retrieval 1.4.2013)

- **L2CAP Resource manager**

  The L2CAP Resource manager handles PDU fragments by arranging them in their order and sending them to the Baseband. L2CAP Manager is designed to help with this because the controller has a limited buffering capability. The L2CAP also helps in making sure that the SDUs sent are compliant with the parts of negotiation. (Bluetooth SIG, Core System Architecture, date of retrieval 1.4.2013)

3.4.3 Host to controller interface (HCI)

This is the interface between the controller and the Host system. The HCI is designed to help the controller in managing packets by segmenting and fragmenting PDUs for transportation. This is because of the limited data buffering capability of the controller. (Bluetooth SIG, Core System Architecture, date of retrieval 1.4.2013)

4 BLUETOOTH LOW ENERGY (BLE)

Bluetooth Low Energy is a technology integrated into the Bluetooth core aimed at applications that run on devices that operate on coin-cell batteries. It is also aimed at devices that have a lower complexity and a lower cost. These devices are called smart devices. Bluetooth LE applications consume a fraction of energy of a classical Bluetooth application making the device battery life-time last for months or years.

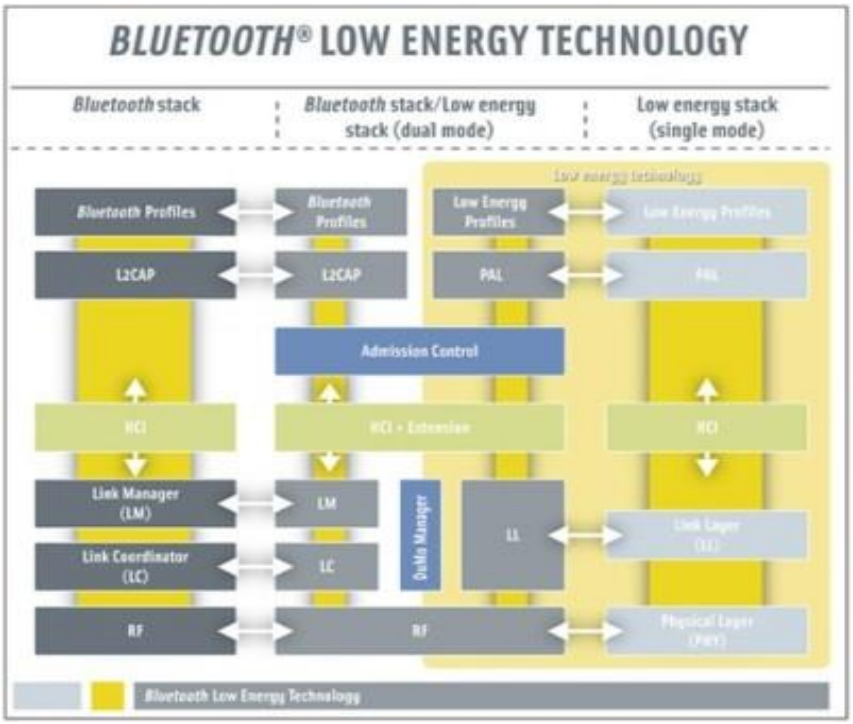

FIGURE 6. Bluetooth v4.0 core specification (Sean Hollister 2010, date of retrieval 10.4.2013)

The Bluetooth core system is made up of a RF transceiver, a baseband, and a protocol stack. This technology offers a service that makes devices connect with each other and data being exchanged or transferred between these

devices. Bluetooth 4.0 is the latest version of Bluetooth wireless technology with the Low Energy introduced incorporated (Wikipedia, Bluetooth Low Energy, date of retrieval15.4.2013).

4.1 Bluetooth 4.0 technical Information

Bluetooth Low Energy was introduced in Bluetooth 4.0 in order for devices like watches and toys to be Bluetooth enabled. Other devices include entertainment devices, keyboards, sports and fitness, health care etc. Bluetooth v4.0 core system is a three in one system. It has Classic Bluetooth technology, Bluetooth Low Energy technology, and speed technology which in other previous versions of Bluetooth are not combined but are used separately in different devices according to the device functionality (Bluetooth SIG, Low Energy, date of retrieval 7.4.2013). There are five main features of Bluetooth Low Energy:

- **Ultra-low peak, average and ideal mode power consumption**

  It switches off radio links when no data is transferring between enabled devices.

- **Ability to run for years on coin-cell batteries**

  It consumes a fraction of classic Bluetooth power.

- **Low Cost**

  It is designed for low cost applications.

- **Multi-vendor Interoperability**

  It can operate in single-mode and dual-mode implementations.

- **Enhanced Range**

  With Bluetooth LE the range or distance can be beyond the normal 10 meters of the classic Bluetooth. For example, if the application is a sensor application for security in very big premises, then optimization is needed for an absolute coverage. It can be optimized beyond 200 feet.

(Wikipedia, Bluetooth, date of retrieval 9.4.2013)The normal classic Bluetooth transmits data in 79 channels with 1MHz space between the channels but Bluetooth Low Energy operates in 40 channels with 2MHz space between the channels but in the same spectrum range as the classical Bluetooth (2402-2480MHz).

Bluetooth Low Energy uses a digital modulation technique or a direct frequency spread spectrum which is different from the classical Bluetooth FHSS. It is designed for both single-mode and dual-mode implementations.

For Dual-mode devices, Bluetooth LE functionality is integrated into the Bluetooth core design, making the feature to share some functionality or technology of classic Bluetooth, e.g. Radio and antenna. The Low Energy protocol stack integrated enhances the Bluetooth core.

In single-mode implementation it is not incorporated into the Classic Bluetooth core but it is a stand- alone technology.

4.1.1 High Speed

In April 21 2009 the Bluetooth SIG came up with the version 3.0 + HS. The Bluetooth version 3.0 + HS can transfer data up to 24Mbit/s through the 802.11 wireless LAN radio. It takes 3ms to transfer data and after transferring the data the connection is broken (Wikipedia, Bluetooth, date of retrieval 4.4.2013).

The Bluetooth Radio is used to discover Bluetooth enabled devices, create a connection and to configurate a profile, but data is transferred through an alternate link MAC/PHY (AMP) 802.11

This great achievement in speed has added to a more efficient transfer of data between devices that are high speed enabled than earlier when they were not. Below there are all parts of the enhancements in Bluetooth 3.0 + HS. (Wikipedia, Bluetooth, date of retrieval 9.4.2013)

- **L2CAP Modes**

  The L2CAP Enhanced Retransmission mode improves the performance of the link, makes the link reliable while the streaming mode is unreliable, does not support re-transmission of data and does not support flow control. (Wikipedia, Bluetooth, date of retrieval 9.4.2013)

- **MAC/PHY**

  The MAC/PHY feature is used to transfer data over the 802.11 high links instead of the Bluetooth Radio which has a low power connection. This also helps in the security of the radio because they are only needed to transfer data between devices that are high speed enabled if there is a need but they power down the radio if no data is transferring. (Wikipedia, Bluetooth, date of retrieval 9.4.2013)

- **Unicast connectionless data**

  Unicast connectionless data is added to help in transmitting data without making any initial logical connection with the device involved. This is designed for a small amount of data needed to be sent quickly and requiring a low latency. (Wikipedia, Bluetooth, date of retrieval 9.4.2013)

- **Enhanced power control**

  The enhanced power control has helped in dealing with a link lost observed while listening to the radio or music with your headset. This signal lost

happens when your phone is in your pocket with the headset side inverted. The enhanced power control achieves this by making a power control to be fast. (Wikipedia, Bluetooth, date of retrieval 9.4.2013)

4.1.2 Enhanced Data Rate

(Wikipedia, Bluetooth, 10.04.2013) Bluetooth version 2.1 improves pairing between devices and also increases security. It also improves an inquiry response with Extended Inquiry Response (EIR), making it easier for a device filtering. EIR includes the following:

- **The local name of the device**

  This is the name of the device which by default is the name the manufacturer of the device defined, but it can be changed by the owner.

- **Transmission power**

  Transmission power is used to calculate a distance between two responding devices to know which device is closer to the device that is inquiring. It is also used with RSSI (Received Signal Strength indicator) to calculate a path loss.

- **Service class UUID**

  This is an id that is associated with a specific functionality in a Bluetooth enabled device. For example, a UUID associated with a camera or a video.

- **Manufacturer specific values**

  These are a set of 8-bit bytes which are manufacturer specific.

- **Security**

  Security improvement in Enhanced Data Rate against eavesdropping during pairing is a six –digit passkey. It also eliminates “man in the middle attack”. The model for security pairing is called Secure Simple Pairing (SSP).

- **Lower power consumption**

  Battery life is increased by up to five times. It reduces power consumption.

4.1.3 Frequency Hopping

Adaptive frequency hopping is the technique introduced in Bluetooth Low Energy to diminish interference in an environment where other wireless technologies which fall in the same category, which operates in the same ISM band as Bluetooth, co-exist. The co-existence between technologies that operate in the same unlicensed 2.4 GHz band leads to interference between devices during communication, which dampens the quality of communication. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

- **How it works**

  The below image shows a collision occurrence in the first Bluetooth devices that uses FHSS. These devices use 79 channels in the 2.4 GHz band, hopping 1600 times per seconds across the channels resulting in a collision when another technology in the same band is introduced. A collision can never be avoided in this type of data transmitting technology, resulting in poor quality of service most significantly in voice data.

This is an illustration of a scenario where WLAN and Bluetooth are in operation. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

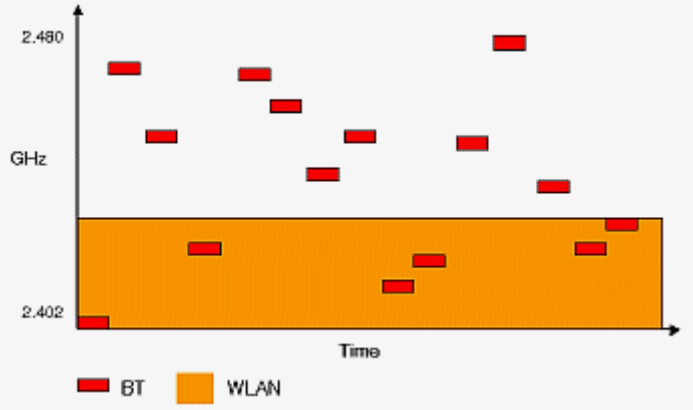

FIGURE 7. Example of how collision occurs in FHSS. (*Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)*

The diagram above is an illustration of a scenario where WLAN and Bluetooth are in operation but with Adaptive Frequency Enabled.

Adaptive Frequency eliminates interferences from the channels that are used, making Bluetooth to adapt to its environment. This success is achieved by re-mapping, instead of the previous 79 channels, the channels were reduced to 40 and the hopping rate reduced to 800. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013).

- **Channel Assessment**

  There are two methods for accessing channels in with AFH: Packet Error Rate (PER) and Received Signal Strength Indication (RSSI). (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

- **PER**

  PER is used with RSSI to know the channels that are already occupied and to check for an error by accessing bad channels repeatedly. PER is not as reliable as RSSI in accessing bad channels.

- **RSSI**

  RSSI is better than PER when testing for bad channels but it consumes more power.

- **Same Channel Communication**

The master and slave use the same channels in communicating unlike in the previous Bluetooth technology where the master communicates to the slave through a channel and the slave responds to the master through another channel. This enhancement helps in avoiding the retransmission of data. If the master speaks to the slave through a good channel and the slave responds in a very bad channel, the master has to transmit the same message again to the slave. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

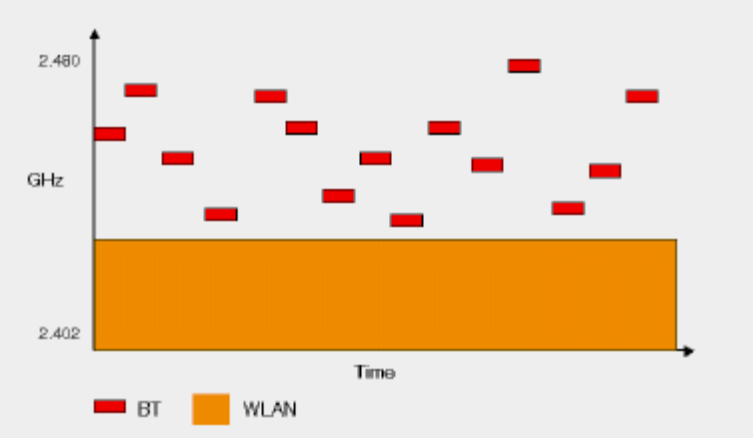

FIGURE 8. Collision free (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013).

Updates are made to the previous version of Bluetooth specification in order to achieve the purposed or conceived idea of interference elimination.

- **Baseband**

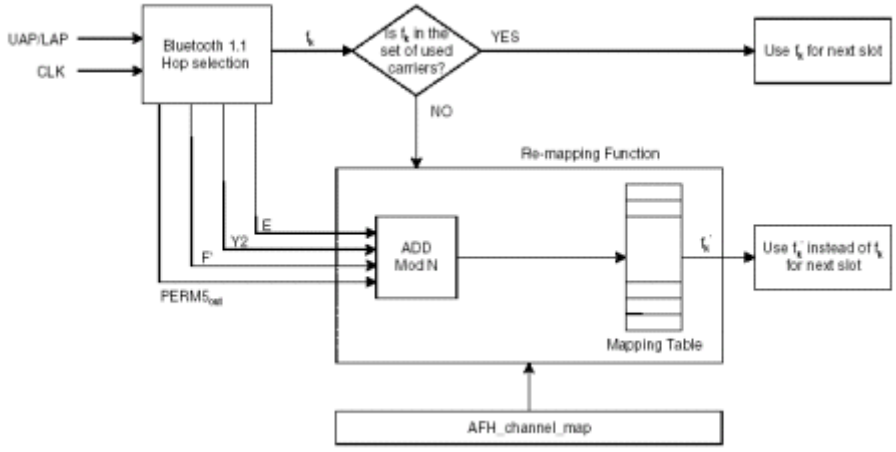

FIGURE 9. The diagram above describes the algorithm used in achieving AFH. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

In some implementations, LMP enables a master device to retrieve information from slaves about channels that are bad, and this information

retrieved is stored and used when the master is generating new sets of hop.

- **HCI**

HCI (Host Controller Interface) modification helps in secluding certain channels that are not mapped for Bluetooth transportation from the ones that are mapped for Bluetooth transportation. It achieves this purpose by using two commands; The first command is used in separating channels while the second command is used by the host device to obtain the chapel map that is in use. (Charles Hodgdon, Ericsson licensing 2003, date of retrieval 15.4.2013)

For example, if a computer is both WLAN and Bluetooth enabled, during a Bluetooth communication the Host Controller will notify other devices that are in the network by issuing a command which restrains the Bluetooth communication via WLAN channels.

4.1.4 Security

There are differences in the security mechanism of Bluetooth Low Energy as compared with BR/EDR. Association models have differences in security but they are similar with Secured Simple pairing which is a feature of BR/EDR.

4.1.4.1 Association Models

There are three types of association models in Bluetooth LE technology (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 17.4.2013):

- **Just Works**

Just Works is used by devices which have a limited I/O power such as headsets and which do not require a user interaction but will prompt a user to confirm pairing when connecting to a device. It does not protect against man in the middle attack therefore making it vulnerable to eavesdropping, but it is much secured than the fixed PIN security implementation used in the similar devices with a limited I/O power. (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 17.4.2013)

- **Out of Band**

  Out of Band mechanism protects against man in the middle attack only. During pairing, the information of the device is exchanged through the use of Near Field Communication (NFC). (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 17.4.2013)

- **Passkey Entry**

  This mechanism is used when pairing similar devices with a numeric key entry or between a device with a numeric key entry and a device with a display such as connecting a keyboard with a computer. There is a 6-digit number which must be entered by the user(s) in both cases to pair the devices. This mechanism protects against eavesdropping. (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 17.4.2013)

4.1.4.2 Key Generation

During pairing in Bluetooth LE the Host device generates the link key for pairing but in BR/EDR the controller is responsible for the key generation. Different keys are generated for different purposes. (Bluetooth SIG, Bluetooth Low Energy Security, date of retrieval 18.4.2013)

a) **Confidentiality and authentication**

This key is generated for both data and device authentication

b) Authentication of unencrypted data

This key is generated for the authentication of unencrypted data only

c) Device identity

This key is generated for device authentication only

4.1.4.3 Encryption in Bluetooth Low Energy

AES-CCM cryptography is used in Bluetooth LE for encryption and it is the controller that is responsible for data encryption unlike in the link key generation where the device is responsible for the key generation.

4.1.4.4 Data security

In Bluetooth Low Energy signed data can be transported between two devices even if the attribute protocol used (ATT) in transporting the PDU is not encrypted. The data is signed with a Connection Signal Revolving Key (CSRK) by the sending device and transported via an ATT bearer. When the receiving device gets the message, it will check the signature on it to know if the packet has come from a trusted device.

The message, which is the code for authenticating the PDU, is generated by the controller‘s counter and the algorithm designed by the system manufacturers. The counter is incremented whenever a packet is signed and sent. This is to avoid sending two or more packets generated with the same signature code. (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 19.4.2013)

4.1.4.5 Privacy Feature

A Bluetooth LE enabled device is hardly tracked because of its constant changing of address. During a re-connection with known devices, the private address used in activating the privacy feature must be made known to the

devices that it is connecting with. The device identity key exchanged during connections is used in generating the private address of the device. (Bluetooth Low Energy Technology Security, SIG group, date of retrieval 19.4.2013)

4.1.5 Usability

Bluetooth Low Energy technology can be found in many devices and has given room for so many devices operating on low power, which once was left out. Low power devices now communicate with mobiles phones, computers, cars, and other electronics household appliances. The medical field most essentially has beginning to witness the greatness of the evolution of Bluetooth Low Energy because of the aging population and the cost of health care, making it easier for doctors and nurses to monitor patients remotely through a sensor communication with a device that is Low Energy enabled.

Bluetooth Low Energy can be used in many applications depending on what the developers want the application to do (use cases). Below are some applications that use Bluetooth Low Energy technology.

4.1.5.1 Sport and Fitness

- **Heart rate monitor**

  In June 2011 Dayton Industrial Co. Ltd one of the world's leading sports and fitness developer and manufacturer of wireless devices announced its first production of Bluetooth LE wireless heart rate monitor. This heart rate monitoring device is compatible with any device that is Bluetooth LE enabled and can be paired with a mobile phone (with Bluetooth v4.0) to display the heart rate data during exercise.

FIGURE 10. Heart rate monitor

The ultra-low power advantage will make the sensor of the device to run on a CR2032 coin-cell battery for 1.5 years when used according to instruction which is 1hr/day. (Nordic semiconductor, Heart rate monitor, date of retrieval 1.5.2013).

- **Stereo Headset**

  Bluetooth v4.0 enhancement in headsets has solved the problem of signal lost, which was the major problem with the earlier versions of Bluetooth. With the earlier versions of Bluetooth putting your mobile phone in your bag or pocket will result in a signal lost or when you are in a location where other wireless technologies are in use, you begin to experience interference, which makes it annoying when you cannot hear properly. The high speed enhancement with the use of limited channels and same channels between the master device and the slave when communicating has helped to eradicate this problem. You can now listen to music with your phone inside your bag or pocket without the fear of signal loss due to the high speed of data transport. (Bluetooth SIG group, date of retrieval 1.5.2013)

FIGURE 11. This is a Motorola device. (Windows phone central store, Motorola MOTOROKR S305 Bluetooth stereo headset, date of retrieval 1.5.2013)

- **Smart phones**

  Bluetooth v.4.0 smart phones can now communicate with low power devices like watches and sensors with Bluetooth Low Energy technology. Watches can now remind you if you forget your mobile phone at home, in a car or wherever the moment you leave the coverage area. Also if you are in a meeting and your phone is ringing, you can easily reject the call by simply tapping the reject call button on your watch instead of dipping your hand in your pocket to get the phone out before rejecting the calls. Your watch can also notify you when a text message comes into your phone.

  The below device is a Casio G-Shock Bluetooth Low Energy Smart Watch, which when connected with iPhone 5/4S notifies you of incoming calls, text messages and emails when the mobile phone is in vibration mode and is inside your pocket or jacket. It is also used to track your mobile phone and reminds you by beeping or alarming if your phone is not with you. (Gear patrol, Castrol G-Shock Bluetooth Low Energy Smart Watch, Date of retrieval 4.4.2013)

FIGURE 12. A watch that is Low Energy enabled. (Gear Patrol, Casio G-Shock Bluetooth Low Energy Smart Watch, date of retrieval, 1.5.2013)

4.1.5.2 Plant monitoring

Soon we will start monitoring our plants with an application that uses a push notification and a wireless sensor. This technology is on its way but the date has not been announced. Pairing the sensor with a smart phone or a tablet that is Bluetooth Low Energy enabled, which runs the application for monitoring plants helps you to know when your plant is lacking elements. This helps you in monitoring the growth of your plant as well as measuring the amount of sunlight, moisture, temperature and fertilizer, which are very essential for the plant. For example, if the temperature of the environment where the plant is kept is uncongenial for the plant, you will get a notification telling you for example, that the plant is lacking sunlight.

The picture below is an example of what has been explained in the previous paragraph. The sensor is planted in the soil inside the pot, the mobile phone gets a notification whenever there is lack of mineral elements, water of sunlight. (Nancy Taplett 2013, date of retrieval 10.4.2013)

FIGURE 13. Plant monitoring application running on the mobile, communication with sensor

4.1.5.3 Health

The health sector has greatly benefited from the development of Bluetooth Low Energy which has helped to reduce cost and also improves better patients and disease management. Patients who forget to take their medications prescribed by the doctor because of sickness or age are now reminded by their mobiles when the time for medication.

With the help of Asthmapolis (a medical application for Asthma) asthmatic patients can now be monitored by their doctors and nurses if they used the inhaler at the appropriate time prescribed by the doctor. A sensor is attached to the inhaler which monitors the patient and sends the data to the mobile phone which sends the data to the hospital information system which can be access by the nurses or by the doctors. (Jeroen Gaudissabois 2013, date of retrieval 4.4.2013).

The below diagram is a home application illustration of how data is collected and then transported to the medical centered.

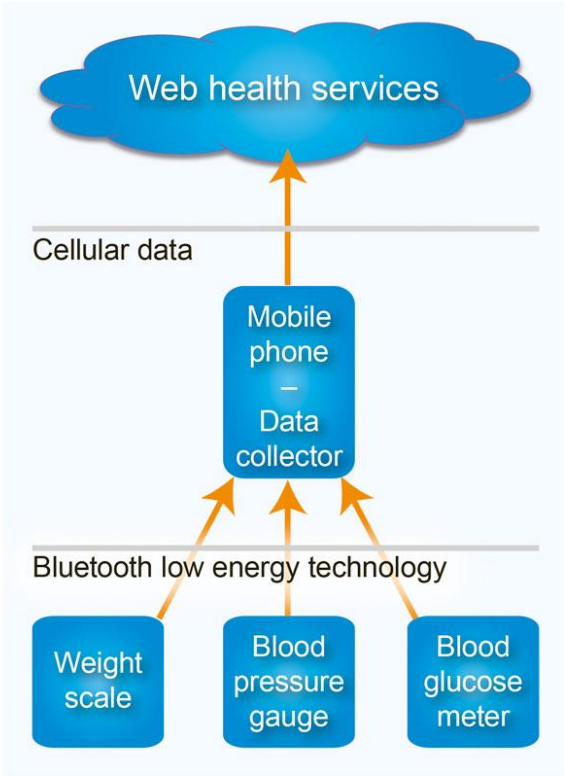

FIGURE 14. A home healthcare illustration (Rolf Nilsson & Bill Saltztein, Medical electronic design, date of retrieval 4.4.2013).

5 BLUTOOTH LOW ENERGY VERSUS CLASSIC BLUETOOH

Bluetooth v4.0 is ideal for a small data transfer and for a periodic transfer of data. Applications can now be built to run on a Bluetooth Low Energy enabled device communicating with sensors and accelerometers. There are differences between these two technologies.

5.1 Single-mode and Dual-mode

Bluetooth Low Energy is designed for both dual-mode devices and single-mode devices. A single-mode device is a device that is Bluetooth Low Energy enabled without Classic Bluetooth implementation on it, while a dual-mode device is a device that has both implementations on it. An example of a single-mode device is a sensor and an example of a dual-mode device is a mobile phone.

The single-mode implementation is specifically designed for a low cost, low power consumption and small packet transportation. With the help of sensors that are Low Energy enabled, patients can be effectively monitored.

Dual-mode devices consume power when using the Classic Bluetooth but save power when the Bluetooth Low Energy is used. From the table below, it shows that if Classic Bluetooth consumes a power of 1, Bluetooth Low Energy will consume a power of 0.01-0.05 depending on the application or use cases.

5.2 Difference in profiles

(Rolf Nilsson & Bill Saltztein 2012, date of retrieval 01.04.2013) These two technologies use different profiles for a connection. GATT (generic attribute profile) is used by Bluetooth Low Energy for connection between two devices that are Bluetooth Low Energy enabled while Classic Bluetooth uses SPP (serial port profile) for a connection. Devices connect with each other when they have the same profile, therefore a Classic Bluetooth enabled device cannot connect with Bluetooth Low Energy enabled device because of their difference in connection except for the profiles that are supported by both technologies.

SPP simulates a serial port connection. Examples of profiles that are not supported by Bluetooth Low Energy are FTP, A2DP, OBEX, VDP and HSP.

5.3 Master and Slave connection

In Classic Bluetooth a master can connect up to seven slaves in a piconet but in Bluetooth Low Energy technology a master can connect to as many slaves as possible depending on the application and the memory of the device. In Bluetooth Low Energy technology the slaves, before sending data, have to announce to other devices that are in the network that they have something to send during the scanning of the other devices (Rolf Nilsson & Bill Saltztein 2012, date of retrieval 1.4.2013).

5.4 Low Power

Bluetooth LE's big advantage over classical Bluetooth is the ability to consume a very small amount of power. For example watches and sensors that operate on coin-celled batteries are able to last very long without charging. This is because the protocol of Bluetooth LE is designed to allow low duty cycle and also the use cases. Constant transmission of data with a Bluetooth LE device will result in excess power consumption. This is because the device is designed for Low power devices (Rolf Nilsson & Bill Saltztein 2012, date of retrieval 01.04.2013).

5.5 Common features

Bluetooth Low Energy inherited some features of Classic Bluetooth technology. Both of them use the same L2CAP interface and the same AFH. They also use the same security implementation, authentication and encryption (Rolf Nilsson & Bill Saltztein 2012, date of retrieval 1.4.2013).

5.6 Limitations

A stream video with Bluetooth Low Energy connections will consume as much power as Classic Bluetooth or even more. This is because it is designed for applications that run on a cell-coin battery which consume a small amount of energy. Below are more differences between the classic Bluetooth and the

Bluetooth Low Energy technology. The technical specifications are shown in tabular form (Rolf Nilsson & Bill Saltztein 2012, date of retrieval 1.4.2013).

Technical Specification	**Classic Bluetooth**	**Bluetooth Low Energy**
Distance	100m	100m
Data Rate	1-3Mbit/s	1Mbit/s
Application Throughput	0.7-2.1Mbit/s	0.27Mbit/s
Nodes/Active slaves	7	Unlimited
Security	56-128 bit	128 bit AES
Robustness	FHSS	FHSS
Latency	100ms	Less than 6ms
Total time to send data	100ms	3ms
Voice capability	Yes	No
Network topology	Point-to-Point and Scatternet	Star-Bus, point-to-point
Power consumption	Reference value(1)	0.01 to 0.5 depending on the use case
Peak current consumption	Less than 30mA	Less than 20 Ma
Service discovery	Yes	Yes

Profile concept	Yes	Yes
Primary use cases	Health care, audio streaming, mobile phones, gaming, headsets, Personal computers, automotive, sports, security etc.	Health care, audio streaming, mobile phones, gaming, headsets, Personal computers, automotive, sports, security etc.

(Wikipedia, Bluetooth Low Energy, date of retrieval 1.4.2013)

6 BLUETOOTH LOW ENERGY FOR ubiHOME PROJECT

In the United States, children who have old parents living in their homes now monitor them remotely. It can also be applied to in the ubiPILL project either in a hospital environment or at home.

The sensors that are Bluetooth Low Energy Enabled and paired with Bluetooth v.40 mobiles can now be used to monitor aging people and sick people remotely. Bluetooth technology supports a star network topology which makes the mobile phone or a computer to be the data collecting device. For example, an aging woman or sick a patient who lives in her own house can be monitored effectively, remotely with the help of a sensor which runs on the low energy technology paired with a mobile phone that is Bluetooth Low Energy enabled. The application can work as follows: When the patient's time to take her/his medicine has reached, she/he will be reminded by the alarm in her/his mobile phone as programmed by the nurse or doctor. The sensor will keep a watch on when the drawer or cabinet where her/his medicine is kept is opened. If it is not opened It tells that she has not taken her/his medication and will get a reminder notification from the central unit, where information is stored, in the hospital, that she should take her/his medication or it will be seen that at the same hour after a few reminder that she has declined to take her medication. But if she/he takes her medication, then the mobile phone will forward the information to the central unit, where the doctors and nurses can see that she/he has taken her/his medication. For a sick patient, the doctor or nurse will be able to monitor her/his development, if she/he is improving or not after having taken her medications as instructed by the doctor.

In a hospital environment, the nurse gets a reminder to give a certain patient medicine, after he/she has given the patient medicine, the information will be forwarded using the Low Energy feature to the doctor so he/she could see that the patient has taken her/his medicine and if an excess dose is given, the sensor will be able to detect that she/he has taking an over-dose and that

information will be seen by the doctor or it can also stop the patient from taken over-dose by alarming.

A sensor and a mobile phone with Bluetooth Low Energy technology can also be used in a hospital environment for security. It can be used to keep sick people from entering into a dangerous or forbidden room against electrocution or corrosive chemicals. If a sick patient leaves her room and walks into a room which she/he is not authorized to enter, the nurses will get an alarm on their mobile phone and they can also see the particular room the patient has entered.

6.1 Bluetooth Low Energy versus Zigbee

(Brian Dorlan 2009, date of retrieval 8.5.2013) Continua health care alliances picked Bluetooth Low Energy technology and Zigbee above all other low power consuming technologies designed for health care assistance and sports & fitness. Bluetooth Low Energy was picked for its low power mobile devices which are on their way and also for heart rate sensors and monitors while Zigbee health care technology was chosen for sensors that are used for detecting motion or bed pressure.

Both of these wireless technologies are the standards for telehealth application development, but there is a big difference between the two which makes them useful on their applications. Bluetooth Low Energy was designed for ultra-low power devices in a personal area network (PAN) or body area network (BAN), in a star network topology (Karl T 2010, date of retrieval 10.4.2013). The mobile phone is the central device with which all other devices within the coverage range are connected to.

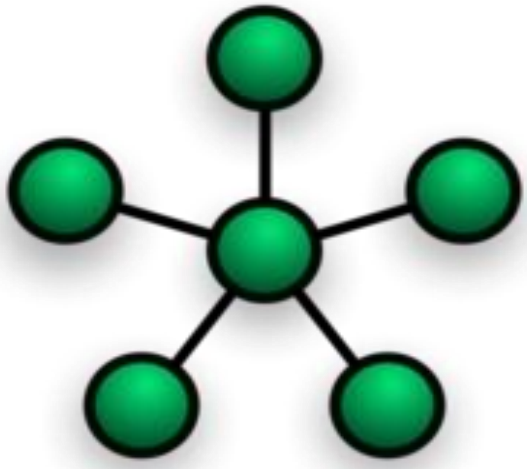

FIGURE 15. Example of a Star topology (Wikipedia, Network topology, date of retrieval 4.5.2013)

The picture above is an illustration of a star topology. The mobile phone sits in the middle and communicates with other devices (slaves) that are within that coverage, collecting data from them and displaying to the user.

Bluetooth Low Energy is preferred to Zigbee because of the following reasons:

- **Power consumption**

  The power consumption between these two technologies is much higher on the side of Zigbee technology. Zigbee consumes 185.9UW/bit while Bluetooth Low Energy consumes 0.153UW/bit (Zigbee versus Bluetooth LE, date of retrieval 4.5.2013).

- **Topology**

  Star topology best suits hospital network in a hospital environment and also at home. The picture below is a mess network illustration which is supported by Zigbee technology (Zigbee versus Bluetooth LE, date of retrieval 4.5.2013).

  .

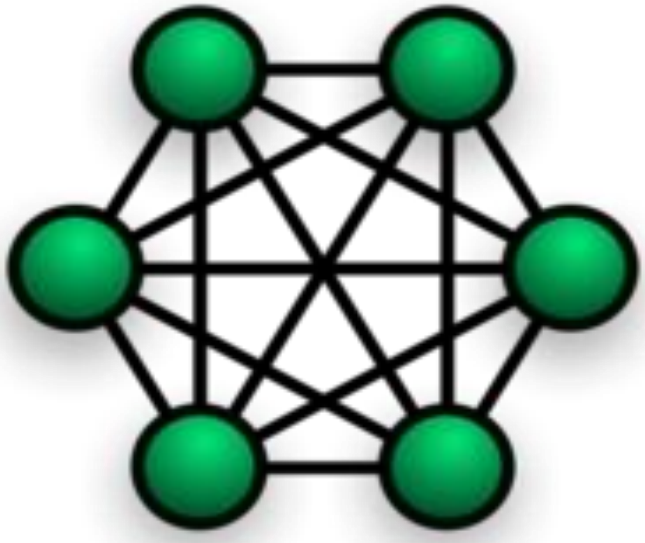

FIGURE 16. Example of a Mesh topology (Wikipedia, Network topology 4.5.2013)

This type of network topology is very expensive and the set-up and maintenance is too difficult. It also has high chances of redundancy in the connection and the administration of the network is too difficult.

- **Hardware Support**

  Bluetooth technology is supported by millions of devices and in the up-coming devices the dual-mode will be included while it is in some con-sumer electronics and remote controls (Zigbee versus Bluetooth LE, date of retrieval 4.5.2013)

- **Modulation**

Bluetooth Low Energy technology uses adaptive frequency hopping which helps in finding clear channel to help saving a battery life while Zigbee uses DSSS (direct frequency spread spectrum) and keeps trying to send packets until a packet is delivered (Zigbee versus Bluetooth LE, date of retrieval 4.5.2013).

- **Bit rate**

  The set-up time for Bluetooth Low Energy is 3ms while the set-up time for Zigbee is 20ms.

7 CONCLUSIONS

The increased number of aging population and sicknesses called for the innovation of remote monitoring. Remote monitoring has helped to reduce costs and has made it easier for doctors and nurses to remotely monitor patients more effectively.

Bluetooth Low Energy innovation is an amazing technology which will surely be the leading technology for years to come in healthcare services. Interoperability between millions of devices is something many wireless technologies are still finding difficult to achieve, making it easy for different devices to communicate with each other using Bluetooth technology. The products using this technology will consume a fraction of power of Classic Bluetooth and are able to operate for years without recharging.

The Bluetooth SIG will keep developing this technology even by taking it higher beyond what it is now. With the quality of time spent in researching and studying about Bluetooth Low Energy technology I am convinced that this is the best technology for telehealth applications because of the numerous advantages it has over all the wireless technologies that are existing today; low cost, interoperability, maximum security and high speed. Most other technologies consume a lot of power, and not many devices are supported.

I am glad to have this as my thesis topic, I have learned a lot about Bluetooth technology in general since getting this topic, which will help me in my pursuit for a career in wireless technology.

Thank you for taking your time to read my thesis and I hope this will help you widen your horizon in Bluetooth and also helps you in your professional life if you are a developer or want to know more about the technology

REFERENCES

Allion, The next Bluetooth wave: High Speed and Low Energy Technology. Date of retrieval 10.4.2013
http://blog.allion.com/2012/01/the-next-bluetooth-wave-high-speed-and-low-energy-technology/

Bluetooth developer portal 2013. Core System Architecture. Date of retrieval 1.4.2013
http://developer.bluetooth.org/TechnologyOverview/Pages/Core.aspx

Bluetooth developer portal 2013: Bluetooth Low Energy Technology Security. Date of retrieval 10.4.2013
http://developer.bluetooth.org/TechnologyOverview/Pages/LE-Security.aspx

Bluetooth developer portal, Security. Date of retrieval 27.3.2013
http://developer.bluetooth.org/TechnologyOverview/Pages/Security.aspx

Bluetooth developer portal, Profiles overview, date of retrieval 10.4.2013
http://developer.bluetooth.org/TechnologyOverview/Pages/Profiles.aspx

Bluetooth SIG, Bluetooth 4.0 with Low energy technology paves the way for Bluetooth Smart devices. Date of retrieval 1.4. 2013
http://www.bluetooth.com/Pages/low-energy.aspx

Bluetooth Extended Response. Date of retrieval 10.04.2013
http://docs.huihoo.com/symbian/nokia-symbian3-developers-library-v0.8/GUID-F2A793F1-A5B5-526B-B147-771D440B13A2.html

Bluetooth Low Energy vs. Classic Bluetooth: Choose the Best Wireless Technology for Your Application
http://www.medicalelectronicsdesign.com/article/bluetooth-low-energy-vs-classic-bluetooth-choose-best-wireless-technology-your-application

Bluetooth SIG, Bluetooth basics, date of retrieval 7.4.2013
http://www.bluetooth.com/Pages/Basics.aspx

Charles Hodgdon May 2003. Adaptive Frequency Hopping for Reduced Interference between Bluetooth and Wireless LAN. Date of retrieval 15.4.2013
http://www.design-reuse.com/articles/5715/adaptive-frequency-hopping-for-reduced-interference-between-bluetooth-and-wireless-lan.html

Continua picks ZigBee, Bluetooth LE for health devices, sensors, date of retrieval 08.05.2013.
http://mobihealthnews.com/2577/continua-picks-zigbee-bluetooth-le-for-health-devices-sensors/

FREE WEEKEND MEMORIAL DAY WEEKEND SHIPPING, Windows Phone Central Store
HTTP://STORE.WPCENTRAL.COM/MOTOROLA-MOTOROKR-S305-BLUETOOTH-STEREO-HEADPHONES/11AA5659.HTM

Gear Patrol. Casio G-Shock Bluetooth Low Energy Smart Watch. Date of retrieval 04.04.2013
http://gearpatrol.com/2013/01/04/casio-g-shock-bluetooth-watch/

Gioacchino B. Rapport Bluetooth technology. Date of retrieval 02.04.2013
http://www.gioacchino.be/project/bluetooth.pdf

Hot HardWare 2011. Bluetooth 4.0 Official Debuts: Low Energy Spec Shipping in Products. Date of retrieval 05.04.2013

http://hothardware.com/News/Bluetooth-40-Officially-Debuts-LowEnergy-Spec-Shipping-In-Products-By-Early-2011/

J. Mander and PICOPOULUS. Bluetooth piconet application. Date of retrieval 02.04.2013
http://www.ee.ucl.ac.uk/~afernand/Example1.pdf

Karl T. 2010. Bluetooth Low Energy vs Zigbee. Date of retrieval 10.04.2013
http://e2e.ti.com/blogs_/b/connecting_wirelessly/archive/2010/03/09/bluetooth-low-energy-versus-zigbee.aspx

Lawrence Harte 2008, Introduction to Bluetooth 2nd Edition. Date of retrieval 4.4.2013
http://www.althosbooks.com/intobleb.html

Parrot flower power 2012. The most advanced plant sensor. Date of retrieval 10.4.2013
http://www.parrot.com/flower-power/

Remnart Technologies.practical applications of diversified technology. Date of retrieval 23. 4.2013
http://remnart.com/2012/01/comparison-between-zigbee-and-bluetooth-low-energy/

Rolf Nilsson ans Bill Saltztein 2011, Bluetooth Low Energy Technology Makes New Medical Applications Possible. Date of retrieval 4.4.2013
http://www.medicalelectronicsdesign.com/article/bluetooth-low-energy-technology-makes-new-medical-applications-possible

Wikipedia. Bluetooth Profile. Date of retrieval 21.4.2013
http://en.wikipedia.org/wiki/Bluetooth_profile

Wikipedia, Bluetooth,Date of retrieval 4.4.2013
http://en.wikipedia.org/wiki/Bluetooth

Wireless dictionary. Bluetooth (tm). Date of retrieval 1.4.2013
http://www.wirelessdictionary.com/wireless_dictionary_bluetooth_definition.html

Wikipedia, Network topology, date of retrieval 4.5.2013
http://en.wikipedia.org/wiki/Network_topology

Zigbee vs. Bluetooth LE, Remnart Technologies: practical application of diversified technology.
http://remnart.com/2012/01/comparison-between-zigbee-and-bluetooth-low-energy/