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浙江大学

Master Thesis

Modular Home Automation Systems for Senior Citizens

Student:
Quing-Wen He Chen

Supervisor:
Honggang Zhang

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Abstract

The aging of the population is one of the biggest challenges in our society. Citizens life expectancy is growing and the birth rate is decreasing. In long-term this is untenable. Thanks to the advance of technology we can try to help to reduce the impact of this problem. I introduce a brief work on Modular Home Automation Systems with energy efficiency adapted to nowadays lifestyle and technology. These systems make use of wireless communications instead of wired ones to minimize the invasion of new devices.

Because of the characteristics of these systems, ZigBee suits perfectly. ZigBee is a specification made to provide low rate wireless communications. ZigBee networks make the communication more efficient and adaptive.

To achieve a modular environment, we use some design patterns from Software Engineering ,which also improve the security and maintainability of the system. The system is also expandable and reliable among other capabilities.

Acknowledgments

To my family for their support and help to let me be who I am now.

My friends and proofreaders to cheer and support me to continue with my duty till the end, especially to Albert, Neus, Haodi, Júlia, David and Christian.

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My Laboratory mates with their stories and jokes.

Especially to my supervisor, Professor Zhang for his advices, comments and challenges.

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Glossary

ACK Ackowledge. 24, 25, 36, 37

API Application Programming Interface. 42

APS Application Support Sublayer. 19

BPSK Binary Phase Shift Keying. 31–33, 67

CCITT Consultative Committee for International Telegraphy and Telephony. 24

CMS Content Management System. 48, 49

CRC Cyclic Redundancy Check. 24, 30

CSMA-CA Carrier Sense Multiple Access - Collision Aviodance. 27, 36

DB Data Base. 42, 45, 53

DSSS Direct Sequence Spread Spectrum. 55

FCS Frame Check Sequence. 24

FFD Full Function Device. 19, 20, 50

GTS Guaranteed Time Slot. 27, 28, 36

HAS Home Automation System. 1–3, 7–13, 15, 16, 42, 46, 49, 50, 53

HVAC Heating, Ventilation and Air Conditioning. 4

ITU International Telecommunication Union. 24

JVM Java Virtual Machine. 45

LAN Local Area Network. 49

MAC Medium Access Control. 19, 23–26, 28, 36, 37

MCPS-SAP MAC Common Part Sublayer - Service Access Point. 28

MLME MAC subLayer Management Entity. 28

MLME-SAP MAC Management - Service Access Point. 28

MVC Model View Controller. 46

O-QPSK Offset Quadrature Phase-Shift Keying. 31, 33, 67

OS Operating System. 45

PAN Personal Area Network. 24

PD Physical Data. 37

PLME Physical Layer Management Entity. 37

PPDU Physical Layer Protocol Data Unit. 23, 36, 37

PSDU Physical Layer Service Data Unit. 37

QoS Quality of Service. 29, 30, 53

RFD Reduced Function Device. 19, 30, 50

WLAN Wireless Local Area Network. 38

WPAN Wireless Personal Area Network. 17, 38

ZDO ZigBee Device Objects. 19

ZDP ZigBee Device Profile. 19

Chapter 1

Introduction

Life expectancy has increased consistently over the last decades. Because of this, the number of senior citizens is increasing and thus they are increasingly older. This fact, attached with the reduction of birth index results in a progressive aging of the population.

The situation aggravates as we consider that women, who traditionally stay home to care for the family, are now joining the labor market. As a direct result of that, the number of people taking care of the elderly is decreasing.

Some of the ways to compensate this problem are:

- Increase/moving/adapting professional assistance.
- Move aged people to nursing homes
- Adapt Homes to Home Automation System (HAS) depending on the requirements of seniors. Thus reducing their level of dependency and let them regain their autonomy.

1.1 Objective

The objective of this work is to introduce the possibility of a HAS system with the following properties:

Adapted to New Technologies: Using Wireless communications instead of wired ones.

Reliability: A trustable system.

Expandable: You can add and remove modules of the HAS to adapt it to your needs.

Low Cost: Chosen Wireless Devices are cheap and for the main system we only need an old computer.

Energy Efficient: Wireless Autonomous devices has limited battery life which is why battery management is very important to enhance the battery lifetime.

1.2 Motivation

Life is always changing, nowadays lifestyle is very different from 10 years ago. One of the reasons is the introduction of new technology in our lives.

Technology helps us to have a more comfortable life. Since ancient times technology has been influencing in our lifestyles. Achievements such as the invention of the wheel, hunting techniques or agriculture have made our life's more comfortable and easy.

Nowadays it is almost impossible to live without depending on any technology or skill, they are everywhere in different purposes and forms. The most common ones are result of aggregation of different techniques with technology having results like cars, phones, airplanes, fridges, microwaves, clothes and etc.

Someday we will become seniors too, it would be good if we can contribute to improve our aging lifestyle. Society has to concern about aging.

From the 3 options to solve the aging problem, the first one is quite expensive. The second is not so expensive but still quite expensive. The third one is a inversion to help elder people to recover their independency or part of it.

Chapter 2

Problem Analysis and Requirements Analysis

2.1 Introduction

Not everybody has the same needs

Everybody ages at their own pace. Someone could start from mobility, another from losing memory... there are different starting points, that is why we want to present a Modular HAS that is designed to cater to each consumer.

2.2 What is Home Automation

Home automation (also called domotics) designates an emerging practice of increased automation of household appliances and features in residential dwellings, particularly through electronic means that allow for things impracticable, overly expensive or simply not possible in recent past decades. The term may be used in contrast to the more mainstream "building automation", which refers to industrial uses of similar technology, particularly the automatic or semi-automatic control of lighting, doors and windows, Heating, Ventilation and Air Conditioning, and security and surveillance systems.

The techniques employed in home automation include those in building automation as well as the control of home entertainment systems, houseplant watering, pet feeding, changing the ambiance "scenes" for different events (such as dinners or parties), and the use of domestic robots.

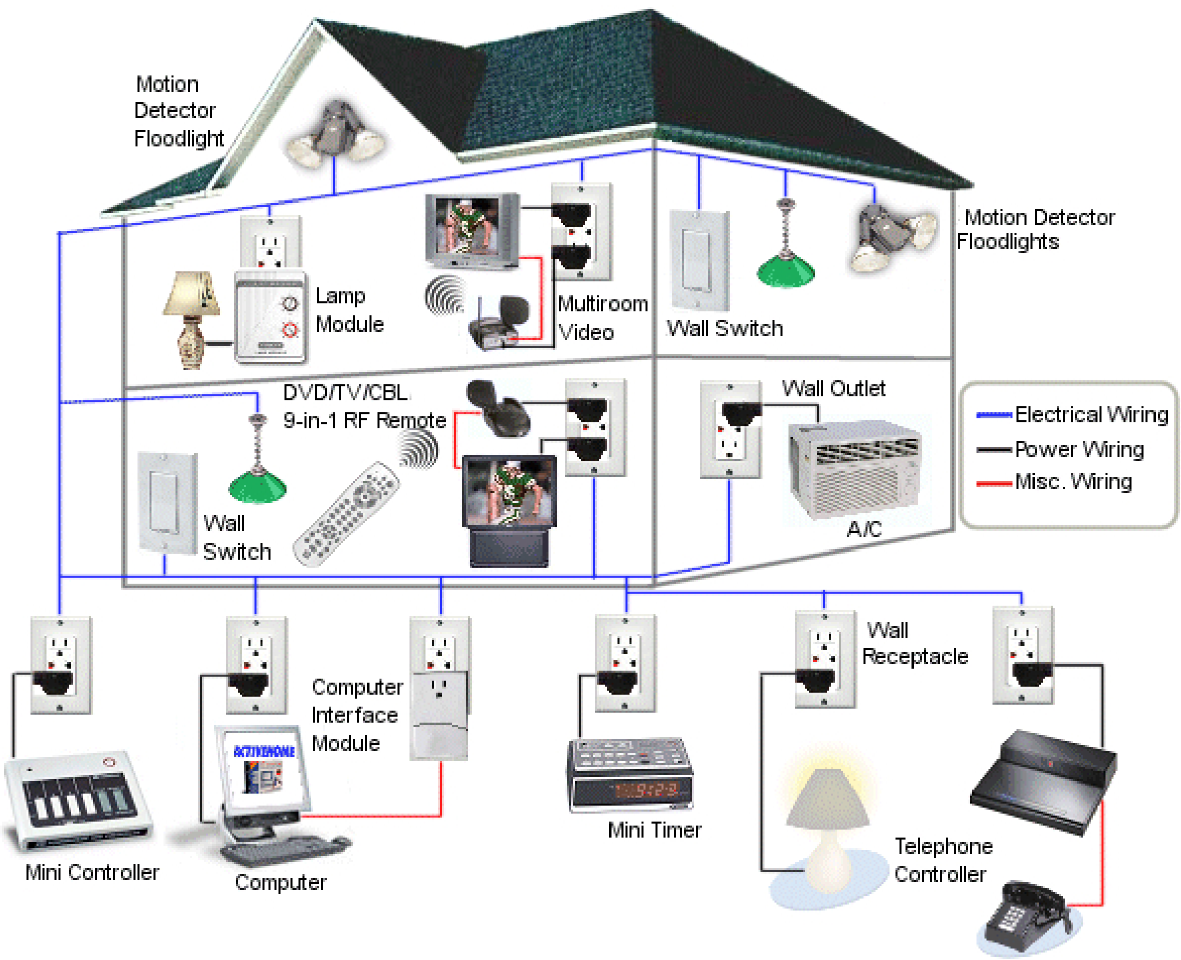

Figure 2.1: General Home Automation Schema

Typically, it is easier to more fully outfit a house during construction due to the accessibility of the walls, outlets, and storage rooms, and the ability to make design changes specifically to accommodate certain technologies. Wireless systems are commonly installed when outfitting a pre-existing house, as they obviate the need to make major structural changes. These communicate via radio or infrared signals with a central controller.

We can take a general view from the figure 2.1:

2.3 Tasks of Home Automation

2.3.1 HVAC

Heating, Ventilation and Air Conditioning (HVAC) solutions include temperature and humidity control. This is generally one of the most important aspects to a homeowner. An Internet-controlled thermostat, for example, can both save money and help the environment, by allowing the homeowner to control the building's heating and air conditioning systems remotely.

2.3.2 Lighting

Lighting control systems can be used to control household electric lights in a variety of ways:

- Extinguish all the lights of the house
- Replace manual switching with Automation of on and off signals for any or all lights
- Regulation of electric illumination levels according to the level of ambient light available
- Change the ambient color of lighting via control of LEDs or electronic dimmers

2.3.3 Natural lighting

Natural lighting control involves controlling window shades, LCD shades, draperies and awnings. Recent advances include use of RF technology to avoid wiring to switches and integration with third party home automation systems for centralized control.

2.3.4 Audio

This category includes audio switching and distribution. Audio switching determines the selection of an audio source. Audio distribution allows an audio source to be heard in one or more rooms. This feature is often referred to as 'multi-zone' audio.

- There are three major components that let you listen to audio throughout your home, or business:

  - CAT 5e/ CAT6 cable from a central audio unit.
  - A keypad to control volume and sources.
  - 2 sets of speaker cabling (4ply from amplifier, and 2 ply from key pad to the speakers).

2.3.5 Video

This includes video switching and distribution, allowing a video source to be viewed on multiple TVs. This feature is often referred to as 'multi-zone' video.

Integration of the intercom to the telephone, or of the video door entry system to the television set, allowing the residents to view the door camera automatically.

2.3.6 Security

Control and integration of security systems.

With Home Automation, the consumer can select and watch cameras live from an Internet source to their home or business. Security cameras can be controlled, allowing the user to observe activity around a house or business right from a Monitor or touch panel. Security systems can include motion sensors that will detect any kind of unauthorized movement and notify the user through the security system or via cell phone.

This category also includes control and distribution of security cameras (see surveillance).

- Detection of possible intrusion.
  - sensors of detection of movement
  - sensors of magnetic contact of door/window
  - sensors of glass breaking
  - sensors of pressure changes
- Detection of fire, gas leaks, water leaks (see fire alarm and gas alarm)
- Medical alert. Teleassistance.
- Precise and safe closing of blinds.

2.3.7 Intercoms

An intercom system allows communication via a microphone and speakers between multiple rooms.

- Ubiquity in the external control as much as internal, remote control from the Internet, PC, wireless controls (e.g. PDA with WiFi), electrical equipment.
- Transmission of alarms.
- Intercommunications.

2.3.8 Other Systems

Using special hardware, almost any device can be monitored and controlled automatically or remotely.

Including:

- Coffee pot
- Garage door
- Pet feeding and watering
- Plant watering
- Pool pump(s) and heater, Hot tub and Spa
- Sump Pump

2.4 Present Home Automation Systems

HAS has been present in private homes since 1980. Before that is was not a commercial technology. Even nowadays it is only present in high standing homes. However, this kind of technology is more and more common to be found in new buildings.

With the crisis on the building sector in countries like Spain, the competition to sell houses grow stronger.

Since the begining, all connections are wired. Fortunately technology is advancing really fast and the introduction of wireless communications is helping to establish new points of view. One of those points of view will be evaluated in this work.

2.5 Description of a Home Automation System

HAS are designed to make our home life more easy and comfortable.

The purpose of HAS is to increase the security of the house, reduce its energy consumption making it more efficient and increase the comfort of the house.

2.5.1 Parts of a Home Automation System

The elements of a domotic system are:

- hardware controllers or software controllers
- sensors
- actuators

Based on their architecture we can separate them into three groups:

Centralized: A centralized controller receives information of multiple sensors and, once processed, generates the opportune orders for the actuators.

Distributed: All the intelligence of the system is distributed by all the nodules that are sensors or actuators. Usually it is typical of the systems of wiring in bus.

Mixed: Systems with decentralized architecture as far as which they have several small devices able to acquire and to process the information of multiple sensors and to transmit them to the rest of devices distributed by the house.

All those HAS has in common the follow:

- One of the task is to sense the medium. That is why there are *sensors*.
- According to collected data, something have to *do something*. That is why there are also *actuators*.

The process from data collection till decision making depends of its configuration (mentioned above)

2.6 Requirements for senior citizens

Advanced aged people have more needs than middle aged people. Due to aging they start losing capabilities. This new support is really important. In nowadays lifestyle, people who work can not take care of their elder because they do not have enough time.

Old people also like to have their own freedom, without feeling controlled. Sometimes it is really difficult to make them change their mind.

With our available technology, we can increase the time of personal autonomy of aged people using HASs specially adapted for them, taking special care in some specific spots or requirements

Aged people tend to gradually lose their sensitive, learning and understanding capabilities.

For old people, it would be interesting to implement solutions that could assist them in matters of:

Security

Anti-Intrusion. Aged people who live alone, often feel unprotected. This causes them to fear a possible undesired intrusion.

Technical security. This is, to detect dangerous situations like water leak, gas scape or important temperature changes.

Mobility and Comfort

Inside the residence. Assistance in domestic tasks.

Outside the residence. Old people can have problems when they have to go shopping, to use public transport or deal with administrative procedures.

Health Care

Health Alarm. To have sanitary assistance in any time they need it or to remind them when they have to take medication.

Health Promotion. Promote exercising and a balanced diet.

Leisure and Entertainment

Communication within close environments. Social interaction with relatives and friends.

Leisure and Entertainment Activities. To fight boredom.

Vocational Activities. To promote personal fulfillment and an active social participation.

2.7 Current Problems

Even though nowadays it is more common to find HASs in normal homes, there are still several big problems around this technology, because of technical limitations and others. We will treat 2 big problems. The first one is the economic limitation and the second one is related to distribution limitation.

2.7.1 Economic Problems

HASs's have been a very expensive technology since the beginning a luxury for a few people.

This software is very specific, so the cost of production is higher than in the case of general purpose software.

Besides software, also hardware is also really expensive, because it is also a very specific one, and should be designed for every residence individually.

To call a HAS company to make the installation in your home can be extremely expensive.

2.7.2 Infraestructure Problems

Until now, HAS is a very static technology, and it comes integrated into equipped homes.

Installing a HAS is really difficult cause you have to almost rebuild your house or residence, sometimes wiring or installing devices and plugs.

Old houses are not built to support a HAS due to their distribution, organization and other factors. There are also physical limitations when you wire a place.

Another problem related with the infrastructure is the proprietary software. If you want to install a HAS you have to contract a company. Different companies products are incompatibles among them.

Chapter 3

Expandable Home Automation System

3.1 Targets and Goals

One of the main target of an Expandable Home Automation System is to cover different scopes depending on the needs and the capabilities of every user.

The system will have to be wireless to acomplish the purpose of low intrusion in the life style. You can get a general idea in the figure 3.1

To achieve this point we need to introduce Modular Software.

3.2 How Can You Get It?

Thanks to the development of new technologies, HAS can increase its consumers as it becomes more popular and easy to install. Thanks to this, even old houses can have its own HAS

Now let's see how HAS can become more popular and cheaper.

If something becomes popular, the cost of production will decrease by optimization. HAS is not an exception. Those systems are attractive cause they can improve our life style, help us save money and takes care of our house when we are not in.

The industry is also aiming to make cheap devices to cover low rate networks, just

Figure 3.1: Possible wireless Home Automation representation

like this case. This is one of the main targets of ZigBee Specification, to cover low rate networks.

3.3 Needed Hardware

After the analysis of the problem and the increase of technology accessibility, it is easy to conclude using a Personal Computer and several Wireless Devices.

3.3.1 Why this decision?

Personal Computers are common to have one or more in every house. We can even use old computers (giving them a new use life) since a HAS does not need a powerful PC. Just one system that can support our program and a Web server (to provide services to local and remote users). Of course this computer may have a ZigBee Module cause it have to communicate with our ZigBee Wireless Devices.

Wireless Devices are chosed cause they are not very expensive and they are also easy to install and not invasive. Without the need to install wires everywhere. Due to their maintenance they are often preferred. In this case we want to use ZigBee Wireless Devices cause it fits really well in this kind of scenario. ZigBee is a low rate data transfer protocol with low cost devices. We will explain ZigBee in chapter 5

Having the central node (PC) and having ZigBee Wireless Devices like sensors and actuators, we have

3.3.2 Personal Computer

A PC is present in more than the 50% of homes. This utility is indubitable. It permits the connection of a lot of I/O peripherals and/or sensors or cameras. It is also computationally powerful and can store a lot of information. Having a Internet Access can open to a lot of interactive services and applications.

In this case, one of its main tasks is to process all collected data from the *Wireless Devices* and to determine which action to do depending on the programmed actions.

The another big task is to attend users, local or remote. Local users differed from remote users not only in location but also in permissions. Local users have more options to configure the HAS and read collected data. Remote Users permissions are mainly to read stored information.

It means that in our PC we will have an interface of communication from Wireless Devices to our HAS and another interface to communicate the HAS with its users. The communication between the Computer and the Users will be through a Web Service. Our HAS will have a Web Server installed.

3.3.3 Wireless Devices

There are several reasons to choose wireless devices over the wire devices: first is the cost effectiveness. Also, the elimination of installing wires through the house. They are more easy to move and relocate than the wired ones.

3.3.3.1 Sensors

Their task is to monitoring determined parameters physicals and chemicals or to detect the accomplishment of determined conditions. They have to sense depending of their features and configuration.

3.3.3.2 Actuators

They have to realize the actions established and sent by the coordinator (our Personal Computer).

Chapter 4

Wireless Devices Problems

4.1 Introduction

Wireless Devices are wireless autonomous devices that can work alone. They have to be to be small and their work is data collection from the environment and data sending to some Base Station to process them.

They are built small cause they may not interfere in data collection (For example, wearable sensors). Some tasks require them to be small, others it do not mind. In our case we prefer them small due to the cost and the intrusion. HAS have not to be intrusive because the goal is to improve our lifestyle, not make it annoying.

There is a deep analysis of Wireless devices in the survey[1].

Here we will describe some of them.

4.2 Battery Life Problem

They are autonomous systems, so they need their supply. Sometimes they can not be connected directly to an electric plug due to their localization. In this case is also very important cause due to devices size it can not be very big so the autonomy is also deprecated.

4.3 Computational Problem

Due to their size and battery problem, the CPU needs to have a low consumption and low cost. Just because the low consumption, it can not be powerful. Those devices CPU are limited to basic operations. Large and complex operations are delegated to the HAS, in our case is our PC.

4.4 Memory Problem

To propitiate to their size, they have also a important memory limitation. They are not storage systems, a small memory consumes less than a bigger one. Smaller the memory is, faster it is. Most of the devices have a small memory for their code (Flash Memory) and another bigger one to storage collected data. Even the second memory is bigger; it can not be compared to a Massive Storage Device.

Chapter 5

ZigBee Specification

5.1 ZigBee Technology

5.1.1 What is ZigBee?

The word ZigBee describes a wireless standardized protocol for Wireless Personal Area Network (WPAN). ZigBee is different to other wireless standards/specifications; it was designed to hold a big market of applications that require low cost and low consumption, with a more sophisticated connectivity than previous wireless systems. ZigBee Specification is focused to a segment of the market unattended by other existing Standards, with low data transmission and low service cycle of connectivity.

The reason to promote a new protocol as suppose to a standard is to allow interoperability between devices made from different companies.

ZigBee is Hardware and Software Specification based on the Standard IEEE 802.15.4. This important standard defines hardware and software. ZigBee Alliance added network layers and application layers specifications to complete the ZigBee stack.

As you can see in table 5.1, ZigBee covers the lack under the spectrum of Bluetooth specification.

5.1.2 How it works?

The standard IEEE 802.15.4 defines 27 channels among three bands. Due to regional support of 868 and 915MHz frequency, is very improbable that only one network can use

Properties of ZigBee IEEE 802.15.4	
Frequency Band & Transference Rate	868MHz: 20kbps 915MHz: 40kbps 2.4GHz: 250kbps
Range	50-100m
Channels	868/915MHz: 11 channels 2.4GHz: 16 channels
Network	Till 2^{64} devices
Temperature Range	-40° till +85° C

Table 5.1: Properties of ZigBee

all 11 channels. However, those two frequency bands are considered close enough to use the same hardware for both of them, this way reduce manufacturing expenses. 2.4GHz physic layer supports 16 channels between 2.4 and 1.4835 GHz with a wide space between channel (5MHz) with the aim to facilitate the requirements of filtering in transmission and reception.

Given that in a home is purpose to have several wireless networks working on the same bands of frequency, the capability of relocation in the spectrum will be an important factor of success.

This standard was designed to implement a dynamic channel selection through a specific selection of algorithms of network layer. The MAC layer includes search functions which follow step by step in a permitted channels list looking for a guide signal. The physic layer contains several functions such as detection of level of received energy , link quality indicators .... Those functions are used by the network to establish a initial channel operation and change channels in response to a long pause.

5.1.3 How ZigBee divides its layers

You can see in the table 5.2 the layers of each model's vision: ISO, IEEE 802 and ZigBee Standard.

5.2 High Layers

5.2.1 Application Support Layer

There are three ISO levels included here: presentation, session, transport.

<table>
<tr><th>7 Layer ISO Model</th><th>IEEE 802 Model</th><th colspan="2">ZigBee Structure</th></tr>
<tr><td>Application</td><td rowspan="5">High Layers</td><td colspan="2">User</td></tr>
<tr><td>Presentation</td><td rowspan="3">Application support</td><td rowspan="4">ZigBee</td></tr>
<tr><td>Session</td></tr>
<tr><td>Transport</td></tr>
<tr><td>Network</td><td>Network</td></tr>
<tr><td rowspan="2">Data Link</td><td>Link Logic Control</td><td rowspan="2">Medium Access Control (MAC)</td><td rowspan="3">IEEE 802.15.4</td></tr>
<tr><td>MAC</td></tr>
<tr><td>Physic</td><td>Physic</td><td>Physic(PHY)</td></tr>
</table>

Table 5.2: ZigBee compared with ISO and IEEE 802

There are 3 basic processes here, that is why this layer used to be divided into 3 sublayers such as:

ZigBee Device Objects (ZDO): node management in the network and routing information among nodes to achieve a correct data transmission.

Application Support Sublayer (APS): the aim of this layer is to process correctly all in/out frames.

ZigBee Device Profile (ZDP): administers tasks association between different network nodes, aka, remote node control using other nodes.

5.2.1.1 Type of devices

There are two types of devices: Full Function Device (FFD) and Reduced Function Device (RFD):

FFD can work in all topologies, they can communicate with whichever device and they also can work as network coordinators. In fact, one of them has to work as Central coordinator of the network (only one).

RFD can only work in star or tree topology and never can work as coordinators due to their reduced function. That is why they can only communicate with a network coordinator or with a FFD who is not working as coordinator.

All devices works with 64bits addresses but still can work with 16bits long addresses due to reduce the size of the packet and if there is no need more nodes than 16bits can address.

Depending on the topology, we have different ways to differentiate nodes:

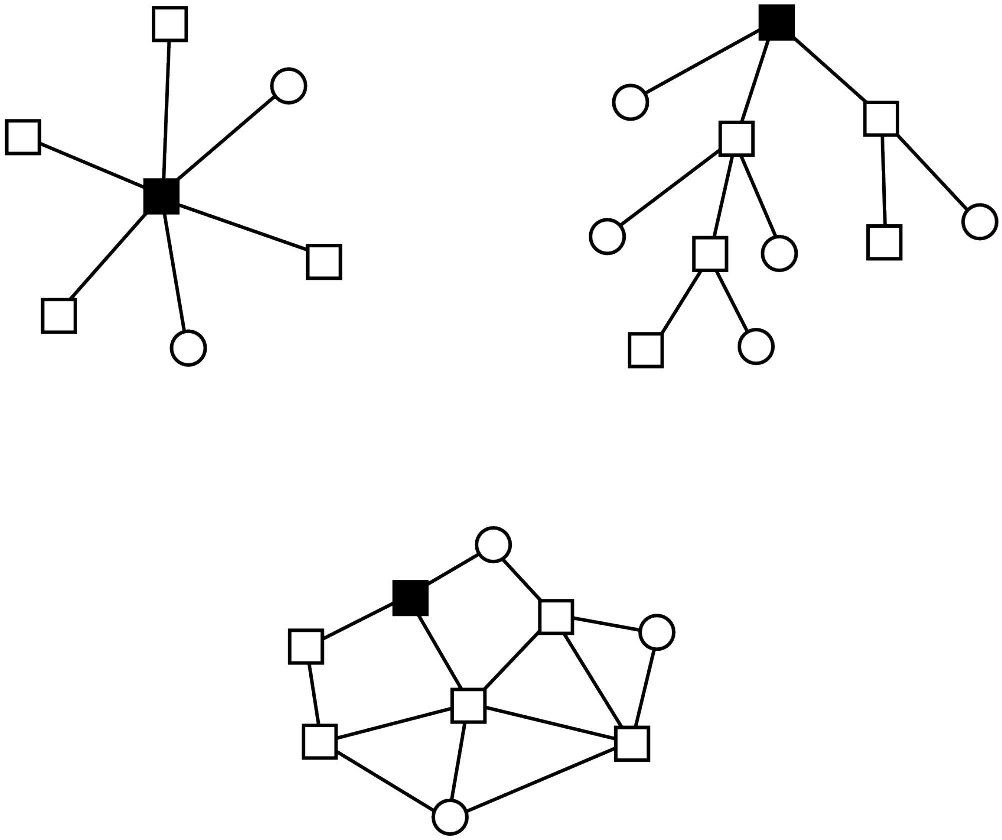

Figure 5.1: Example of Star, Tree and Mesh Topology where the black square represents the Network Coordinator (a FFD device), White squares are FFD devices and circles are RFD devices.

Star: It sends a Network Identification Number followed by destination device's ID. In other words, it sends a NID number which identifies all the network and a DID number which identifies a concrete device.

Mesh/Tree: It sends the ID of origin and destination device.

5.2.1.2 Topologies

ZigBee supports different topologies as you can see in the figure 5.1

Star:

This network has a central node, which is linked to all other nodes in the network. All messages travels via the central node. Notice that at least the central node may be a FFD.

Tree:
This network has a top node with a branch/leaf structure below. To each destination, a message travels up the tree (as far as necessary) an then down the tree.

Net/Mesh/P2P:
A Mesh network has a tree-like structure in which some leaves are directly linked. Messages can travel across the tree, and then a suitable route is available.

5.2.1.3 Network Function Mode

Communication modes in LAN makes reference to data treatment in the network, aka, how and under what circumstances transmit data.

Basically we have two main categories of function mode:

Data Caption
Is based in how the data flows from terminals to the coordinator. There are 3 basic types of data caption: *periodic sampling*, *event driven* and *store and forward*.

Bidirectional Transmission
Consists in systems who require bidirectional communication between terminals and the coordinator. Basically this mode is used with actuator systems and not in sensor systems. There are 2 modes: *polling* and *on demand*.

Next, we explain each mode in detail:

Periodic Sampling

This mode is appropriated on sensors who have to transmit periodically collected data cause they are crucial for the correct performance of the system. Time between 2 data samplings depends on the application who is working. This periodicity changes depending on the conditions of the measured system, so it could be interesting if we can achieve a terminal who can adapt to this change. This way we can reduce oversampling and increase the efficiency of the system and network.

Event Driven

Is used in alarm style applications, presence sensors or some similar application in which we have to transmit data immediately cause the sensor detected a external ”activation” but there is no need to transmit from time to time.

Store and Forward

Intended for applications in which there do not need to send the information immediately but we want going storing sampled information and send it when it reaches a certain threshold and send them all together.

This is a way to check a posteriori that the process has been done within our desired parameters, therefore is a quality control system.

Polling

This mode have several steps. In the first step all terminals are associated to the coordinator. After the network coordinator goes questioning node by node and asking them to send needed data, this is done sending a frame to everybody which includes the ID of the terminal who have to send the information.

On Demand

This model transmits data depending on the demand of a mobile coordinator node, ergo we have a node who can go changing networks and every time it connects to a new network will send a petition of data and after, maybe it will leave again the network. An example can be a person with a PDA moving through a factory, a hospital, etc. and who will gather data from different areas of the factory or patients.

ZigBee specification establishes 3 typical network function modes depending on the destined application. They are equivalent to 3 of before commented modes but with some differences.

Periodically send:
It consists in sending samples from time to time defined by the application. A clear example is a sensor network.
This mode uses a system of signaling to activate the sensor, it will check if there are messages for him and will go back to sleep after accomplish entrusted tasks (transmit data if required).
This mode is related with *periodic sampling*.

Intermittent send:
It sends data when an internal stimulation is detected. Maybe it is just because the coordinator requires data to a terminal or a terminal receives some stimulation (for example it detects a presence of someone, light, etc).
This mode works without any signaling system and therefore do not have to listen continually the channel if have to enter into operation mode, saving a substantial amount of energy.
This mode is related with *event driven*.

Repetitive sending with low latency:

This mode was designed to send data with very low latency and included in some temporal slots. This mode is designed to applications like computer peripherals. This mode can guarantee a minimum transmission time for certain nodes. This is a QoS method in the sense that it can permit to a specific node to transmit without latency during the assigned time.
This more is related with *periodic sampling* even though in this case there have to guarantee low latency.

5.2.2 Network Layer

Network Layer have to implement the following capabilities.

- Start a network
- Connect or disconnect to a certain network
- Configure a new device according to the network operation method without complications.
- Network administrator has to manage the addresses assignment to let new devices to have new addresses.
- Synchronize the network. Using synch signals or pooling.
- Manage security mechanism in frames.
- Route frames to their destinations.

5.3 MAC Layer

5.3.1 Type and Structure of Frames

MAC frames are simple and has only a header, a body of variable length and a queue [2].

Those MAC frames are included in a physic layer's packet, concretely in the Physical Layer Protocol Data Unit (PPDU)'s body.

The header is divided in 3 basic fields:

Header						Body	Queue
Bytes: 2	1	0/2	0/2/8	0/2	0/2/8	Variable	2
Frame Control	Sequence Number	Destination Personal Area Network (PAN) identifier	Destination Address	Source PAN Identifier	Source Address	Frame Payload	FCS
		Addressing fields					

Table 5.3: General Structure of MAC Frames with detailed header.

Frame Control Field (2 Bytes): Specifies the type of frame (there are 3 bits to define the type of frame even there are only 4 types), the type of security, etc. There is an identifier attached to indicate if the frame sender waits for a confirmation (a Ackowledge (ACK) frame).

Sequence Number (1 Byte): It is the identification number of the frame to avoid mistakes between sender and receiver with other frames.

Address Field (0 - 20 Bytes): This field contains those necessary addresses of the network to transmit. However have to take into account that it depends on the network topology and other factors (like the type of frame, etc) to include in this field only the destination address, the origin address or both of them.

The queue consists in a sequence of 2 Bytes of testing (Frame Check Sequence (FCS)) based in a Cyclic Redundancy Check (CRC). Specifically, is a standardized test by International Telecommunication Union (ITU): Consultative Committee for International Telegraphy and Telephony (CCITT) 16-bit CRC

The body's length is variable and its function is data transport of each kind of frame and, therefore it can be divided in several fields depending on the function of the frame.

The frames have been defined to minimize the complexity of devices but keeping a minimum of robustness to be able to transmit in a noisy channel. IEEE 802.15.4 standard defines 4 types of frames:

Beacon Frames: Used by the coordinator to send synchronization signals periodically.

Data Frames: Generic to transmit whatever data type to upper layers.

ACK Frames: To confirm the correct data reception.

MAC Frames: Used by all MAC network control commands

Frame Type Value $b_2b_1b_0$	**Description**
000	Beacon
001	Data
010	ACK
011	MAC command
100-111	Reserved

Table 5.4: Types of MAC and its configuration bits

The table 5.4 shows the bit configuration of those which denotes the type of frame in the control field of the frame. There is a description of the structure of each MAC frame type.

5.3.1.1 Data Frame

The body of the MAC frame is dedicated to data provided from upper layers which have to be send once it is resumed in a physic layer's packet. You can see the format of the frame in the table 5.5

MAC Header			**MAC's Body**	**MAC's queue**
Frame control	Sequence Number	Address Field	Data (0 - 119 Bytes)	FCS

Table 5.5: Data Frame's format

5.3.1.2 ACK Frame

This frame consists in 5 Bytes and it is sent to confirm the correct reception of the received frame. It is only send if the received frame asks for it.

The aim is to have short frames to minimize the network traffic. They have not address field neither in the header nor body.

When a device receives a ACK frame, to know if it is for it cause there is not address field, looks if it was waiting for a ACK frame and if yes, checks if the sequence number is correct.

MAC Header		MAC's Body	MAC's queue
Frame control	Sequence Number	→	FCS

Table 5.6: ACK Frame's format

5.3.1.3 Commands of MAC Layer's Frame

The goal of this frame is to transmit all controls of MAC from one device to another one.

It is composed by two fields: the first one indicates the Identifier of the command and the second is to carry command's data.

MAC Header			MAC's Body		MAC's queue
Frame control	Sequence Number	Address Field	Command ID (1Byte)	Data (0 - 118 Bytes)	FCS

Table 5.7: Command Frame's format

The table 5.8 links each command to its function.

5.3.1.4 Signaling Frame

Signaling Frames are used specifically in transmission mode where temporal slots can be reserved by specific users. They are also used in the process to mount the network, synchronism control, etc. Due to a better understanding of its functionality, we have to explain the superframe functionality mode.

Command ID	Command Type
1	Association Petition
2	Association Petition's response
3	Disassociation Notification
4	Data Request
5	Coordinator Identification Conflict Notification
6	Orphan Device Notification
7	Signal Frame Request
8	Coordinator's Realignment
9	GTS Request
10-255	Reserved

Table 5.8: MAC Command Types

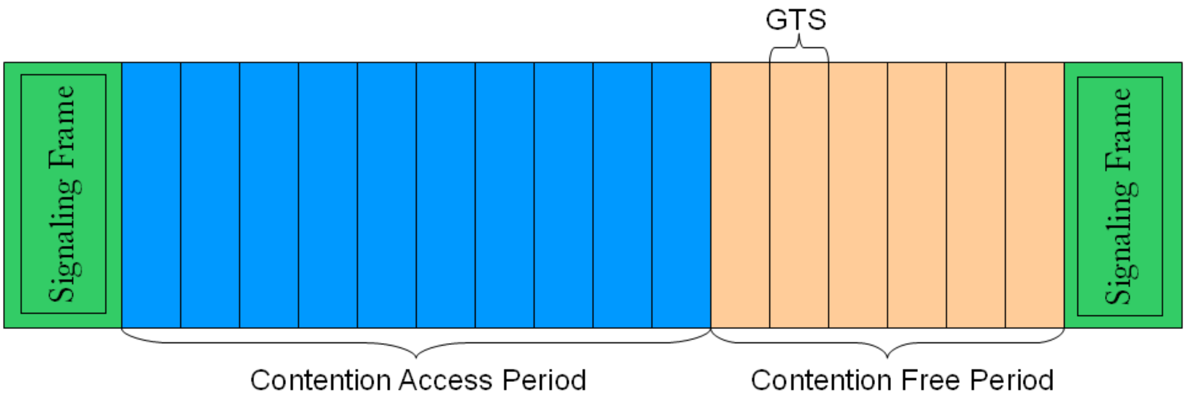

Figure 5.2: Example of signaling frames

Superframe's Structure

The 802.15.4 Standard permits the implementation of superframe structures. This superframe consists in a set of reserved temporal slots (till 16) to certain nodes to transmit. Those 16 slots are preceded by a signalization frame (transmitted by the network coordinator) which transmits the information of which nodes have to transmit in each lost through their ID and in which slots they can transmit. In each slot the assigned node is free to transmit all what it want (data frames, command frames, etc) and as much frames as it can fit the assigned time.

Due to maintain the synchronism and no to overlapping transmissions, there is needed to transmit information about synchronism such as the periodicity of each synchronism frame, etc.

Those 16 temporal slots are divided in 2 parts: *Contention Access Period* and *Contention Free Period*.

The *Contention Access Period* is a period in which all devices can access to the medium using the Carrier Sense Multiple Access - Collision Aviodance (CSMA-CA) method.

The *Contention Free Period* is a superframe's period where some Guaranteed Time Slot (GTS) are reserved to certain nodes (have to take into account that each GTS is 1/6 of the superframe's total duration).

Going back to Signaling Frame's structure, the body is divided in the follow fields:

Superframe Specification (2 Bytes): Contains Superframe's configuration parameters

Pending Specification Addresses (variable length): contains the number and type of addresses of the field list of addresses.

MAC Header			MAC's Body				MAC's queue
Frame control	Sequence Number	Address Field	Superframe Specification	GTS Fields	Pending Specification Addresses Field	Frame's Useful Data Field	FCS

Table 5.9: Command Frame's format

List of Addresses (variable length): Contains a list of addresses of all devices which have pending information to send stored in the coordinator, in other words, device addresses to which the coordinator have to send data once those send a data request.

Frame's Useful Data (variable length): Contains the information, if needed, to all devices of the network in its scope.

5.3.2 MAC Layers Services

MAC Layer offers 2 services to its upper layer. Those services are the *data service* and the *management service*. This service entity is called MAC subLayer Management Entity (MLME), and those two services are accessed using MAC Common Part Sublayer - Service Access Point (MCPS-SAP) and MAC Management - Service Access Point (MLME-SAP).

For each of those services the standard establishes a set of primitives with a series of subfunctions (identical to physic layer's one, seen in the next section). Some of MAC primitives directly use physic layer's primitives but there are others which are specifics from MAC Layer and don't have to access to physic layer.

5.3.2.1 MAC Layer's Data Service

Basically we have 2 kinds of primitives:

- Those destined to transmit (MCPS-DATA).
- Those destined to delete data (MCPS-PURGE).

MCPS-DATA

Composed by MCPS-DATA.request, MCPS-DATA.indication, MCPS-DATA.confirm. The goal is to implement the data transfer. They call Physic

		Primitive's subfunctions			
Primitive	**Category**	**Request**	**Confirm**	**Answer**	**Indication**
GET	Communication Properties	X	X		
SET		X	X		
RESET		X	X		
RX-ENABLE	Radio Control	X	X		
SCAN		X	X		
ASSOCIATE	Network Management	X	X	X	X
DISASSOCIATE		X	X		X
GTS		X	X		X
ORPHAN				X	X
SYNC		X			
SYNC-LOSS					X
START		X	X		
BEACON-NOTIFY					X
POLL		X	X		
COMM-STATUS					X

Table 5.10: MAC Service management primitive's resume

Layer's PD-DATA and it follows the same process of the physic layer (see figure 5.5).

MCPS-PURGE

Contains MCPS-PURGE.request and MCPS-PURGE.confirm. This primitive deletes unnecessary data provided from upper layers or lower layers.

5.3.2.2 MAC Layer's Management Services

This part is centered in MLME primitives, dedicated to manage internally the device in this layer. The table 5.10 shows each management primitive's subfunction, classified. We are not entering in detail of those primitives.

5.3.3 QoS (Quality of Service)

The fact that we want to reduce the complexity of the system drives us the incapability to offer great services in Quality of Service (QoS) level. For example we can not permit sender and receiver to send on the same time and we can not offer different types of services, but we can guarantee temporal slots reserved to a unique device due to decrease the communication latency and also guarantee a total dedication of the network to this device.

We can offer high transmission speed using a low complexity physic layer and we can transmit data till 20Kbps, 40Kbps or 250Kbps. Obviously this speed is high compared to the throughput cause we are not continuously transmitting (reduced duty cycle).

5.3.3.1 Error Control

The standard uses a simple mechanism of full-handshake as the only measure to control errors and QoS. Obviously, all the frames have to request a reception confirmation except broadcast frames (signaling frames, etc) and those from the handshake mechanism. To check that a frame have been correctly received, a simple CRC mechanism is used. In case there is no confirmation or receiving a confirmation saying that there have been a transmission error, the sender have to resend the whole frame.

5.4 Physic Layer

We are going to describe the main parts of this layer. First we are going to comment basic properties of this layer. After we describe the structure of communication packages in physic layer with other devices in the network. The last part describes minimal functionalities of this layer to serve upper layers.

5.4.1 Physic Layer's basic properties

5.4.1.1 Duty cycle

ZigBee was designed to have a extremely low power consumption, but in a radio transmission system is difficult to achieve. Another aim is *low cost* to be competitive.

The solution is to reduce the duty cycle and spend most of the time with RF terminal inactive, achieving a low consumption state. In some applications, senders only needs to be active the 1% of the time.

To make this low duty cycle, the specification provides 2 main function modes:

Using Beacons It permits to assign and reserve transmission time for a certain node.

Not Using Beacons There are 2 operation modes:

- A RFD waits a signal from the coordinator (FFD and who have to be always active).

- The terminal transfers from time to time. This time depends on the application, can be longer or shorter.

Anyhow, in both modes, the duration of the battery is really high and comes limited by the low consumption mode's consumption.

5.4.1.2 Modulation and DSSS

The fact that ZigBee aims a low power consumption and low manufacturing cost carries it to use relatively common and easy to perform modulations. Fewer bits per symbol has a modulation, and keeping constant the inter-symbol distance in the constellation phase and quadrature, lower is the power required to transmit errors compared with a high modulation with more bits per symbol. What is more, to reach this goal, there can only transmit digital data and there can only establish half-duplex communications to not have to keep sender and receptor actives on the same time.

There are 3 possible duty bands: 868MHz, 915MHz and 2.4GHz. The table 5.11 shows the used modulation for each band

Band	Modulation
868/915MHz	Binary Phase Shift Keying (BPSK)
2.4GHz	Offset Quadrature Phase-Shift Keying (O-QPSK)

Table 5.11: Relation Spectral Bands / Modulation

Those modulations satisfies simplicity and easy implementation requirements in relation to other more complicated modulations used in modern communications. Additionally is used a DSSS whichever improves transmission quality cause improves the capacity to receive correctly a signal, but also introduces a bad exploitation of the spectrum. You can see in the Annex a deep description of DSSS and related.

5.4.1.3 Specification of 2.4GHz Band

2.4GHz band uses a orthogonal multilevel kind of signaling (modulation technique called "16-ary almost-orthogonal") which uses a pseudo-random particular sequence of 32-chips to represent a symbol and on the same time achieve a widened spectrum. This ensures a high transmission speed and using at the same time a relatively low symbol tax (minimizing power transmission).

On the other hand, the sequence of 32-chips to transmit is divided in 2 indexations: even and odd. The first one is used to phase transmission and the second to quadrature

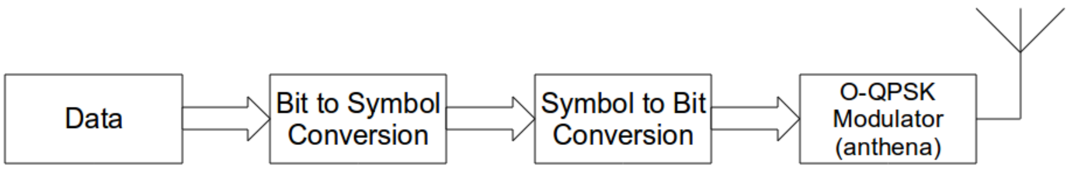

Figure 5.3: Schema of transmission blocks on 2.4GHz

transmission. Moreover, the second has a delay of half time per chip to create modulation offset. Hence 16-chips are used to phase and 16 to quadrature, here the name of ”16-ary almost -orthogonal”.

The process of transmissions consists to convert data bits into symbols (2bits per symbol), separate phase and quadrature information and associate to each of them a sequence of 16 chips. There is no way to apply a sequence of chips to bit per bit, it is always applied to symbol level. The fact of modular and transmitting phase and quadrature separately causes the equivalent of using 4bits per symbol. Each phase or quadrature bit contains the equivalent of 8 chips.

In this band, the standard establishes a symbol rate of 62,5Ksymbols/s, and we transmit 4 bits per symbol we have a total rate of 250Kbps.

Finally the total speed of the chip is 2Mchip/s cause 32 chips are transmitted in 1 symbol time (16μs). Consequently chips speed of one channel (phase or quadrature) is 1Mchip/s.

5.4.1.4 Specification of 868/915MHz Band

This band does not implement any complex codification system either offset. The process it follows is to assign some number of bits to each symbol (1bit per symbols cause in this case the modulation is BPSK [1]) and assign a sequence of chips to each symbol

There is a differential codification stage and what it does is: if the input bit is a “0”transmit to the output of the channel of the RF the bit with the same phase as the bit before, and if the input bit is a “1”, to the output of the modulator BPSK transmits

[1]For more information see [26]

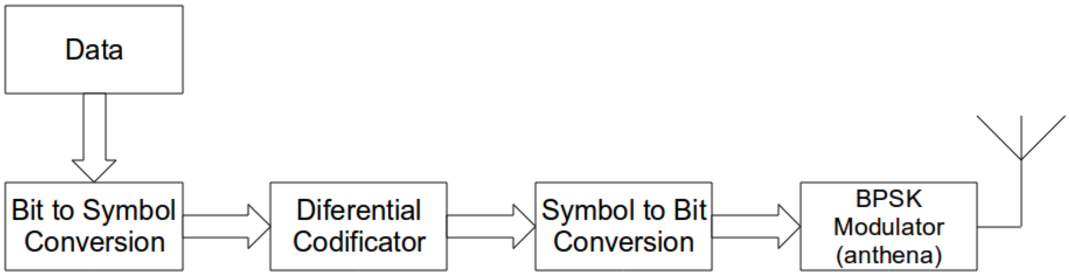

Figure 5.4: Schema of transmission blocks on 868/915 MHz Band

Band	Number of Ch.	Bit Rate	Symbol Rate	Modulation	Chip Speed
868-868.6 MHz	1	20 Kb/s	20 Ksymb/s	BPSK	300 Kchip/s
902-928 MHz	10	40 Kb/s	40 Ksymb/s	BPSK	600 Kchip/s
2.4-2.4835 MHz	16	250 Kb/s	62.5 Ksymb/s	O-QPSK	2 Mchip/s

Table 5.12: Relation between bit rate, symbols and chip speed in each band

the actual bit in contra phase regarding the one before.

For a side the symbol to chip conversion is done to code reversion, i.e a code of 15 chips is transmitted for “1”and the reverse code is transmitted when is a “0”.

5.4.1.5 Spectral Duty Bands and Channel Assignation

IEEE 802.15.4 requires devices to work in 2 spectral bands. The first case (868 and 915 MHz) contains 2 sub-bands so they have to work (getting more compatibility in the market without increase excessively the price of the final product because both bands are close to each other). The second case is the band of 2.4GHz.

The table 5.12 shows the relation among bands, the number of channels of the band and transmission speed of each one.

The decision to choose one band or another depends on the geographic localization and the destined market of the applications cause those mentioned bands are not free in all the countries. In the table 5.13 shows channel assignation depending on the band and regional availability.

Band	Channel	Central Frequency (MHz)	Regional Availability	Additional Limitations
868 MHz	0	868.3	Only available in great part of Europe	No power limitation. The transmission's duty cycle have to be lower than 1%
915 MHz	1	906	This band has free channels in North America, New Zeland, Australia and some countries of South America	Despite some governments can impose some restrictions, in general is not limited either in duty cycle either in power transmission
	2	908		
	3	910		
	4	912		
	5	914		
	6	916		
	7	918		
	8	920		
	9	922		
	10	924		
2.4 GHz	11	2405	This band is free in great part of the world	No limitation either in transmission power either in duty cycle in any geographic zone.
	12	2410		
	13	2415		
	14	2420		
	15	2425		
	16	2430		
	17	2435		
	18	2440		
	19	2445		
	20	2450		
	21	2455		
	22	2460		
	23	2465		
	24	2470		
	25	2475		
	26	2480		

Table 5.13: Channels per transmission band

5.4.1.6 Power Transmission and Receivers Sensibility

The minimum sensibility required by the receptor changes depending on the duty band, though both bands have a small limitations, essentially we need low input signal to work properly. This guarantees the receptor do not have to be anything complicated, reducing the fabrication cost. The table 5.14 shows the sensibility depending on the spectral band.

IEEE 802.15.4 standard do not establish any maximum power transmission, in fact you can use any power transmission. However it establishes the minimum power transmission in -3 dBm to achieve reasonable transmission distances.

Band	Sensibility
868/815 MHz	-92dBm
2.4 GHz	-85dBm

Table 5.14: Relation between needed sensibility of the receiver per each band

5.4.1.7 Selectivity of the Receiver

Because we are using a DSSS system, we do not require a high selectivity. Moreover, IEEE 802.15.4 standard channels are very spaced among themselves (5MHz in 2.4GHz band) compared to their bandwidth (3MHz).

5.4.1.8 Channel Selectivity and Adjacent Channel Blocking

IEEE 802.15.4 establishes a minimum rejection of the adjacent band due to a correct work of the system. On the 868MHz band there is nothing defined cause there is only one channel. For 915MHz and 2.5GHz band established that the receiver system have to reject a adjacent channel of the same power level as the useful one.

On the other hand it also establishes that the system can *reject* those secondary interference channels (those with 2 channels separation from the useful one) till 30dB more powerful than the power of the useful transmission.

In the end the standard also establishes the maximum input signal power of the receptor have to be -20dBm to work without saturation problems either increase of errors rate.

5.4.1.9 Channel Access

Channel Access is managed in MAC layer, anyway the chosen access determines the physic layer cause this one has to implement a lot of features to let MAC manage the channel access. That is why we comment it in this layer.

Medium Access in ZigBee is independent to the type of the network or used topology, it only depends if it transmits using the mode with signal frames (superframe) activated or not. If not we will access to the medium using CSMA-CA type of access. If yes we will use GTS to transmit in case we have a reserved time slot, if we have not reserved time slot to transmit we will use CSMA-CA

5.4.2 Structure of physic layers packages

The physic layer has a defined structure for each package (PPDU). Upper layers frames are resumed in upper layers frames and, therefore, the PPDU is the last encapsulation before channel access and transmit.

PPDU Synchronism Header (40 bits)	PPDU Header (8 bits)	PPDU body (0 - 128 Bytes)

Table 5.15: Generic structure of Physic Layer's data services frames

The table 5.15 shows the structure of the packages which has 3 parts:

PPDU's Synchronization Header (40 bits)
The PPDU's Synchronization Header is independent from the duty band and has 2 basic fields:

- A preamble of 32 logic zeros to let the receiver to synchronize correctly with the sender (remember that those zeros are grouped in symbols and are coded using a sequence of chips, therefore they will not be real transmitted zeros)
- A field to define the begin of the frame and consists in a determined sequence of 8 bits ("11100101" in binary) to let the receiver to establish the begin of the package.

PPDU's Header (1 Byte)
Is a 8 bits header where the highest bit is reserved and the last 7 are destined to advise the length of the package (the maximum length is 128Bytes). Packages between 0 and 4 Bytes and 6 and 7 Bytes are reserved. Packages of 5 Bytes are ACK which contains a ACK's MAC. Packages of 9 or more Bytes are packages with

useful data for physical upper layers. The information referred to ACK's MAC have be seen in

PPDU body (0-128 Bytes)
Is a unique fiend composed by the Physical Layer Service Data Unit (PSDU). It can vary among 0 and 128 Bytes and contains all the useful data of the PPDU, namely data for upper layers.

5.4.3 Physic Layers Services

Physic Layer's services are a set of minimum needed primitives that the physic layer offers to MAC layer.

The difference between primitives and packages may be noticed. Primitives are the set of minimum functionalities which each layer has to offer to upper layers and therefore, are originated in each device. On the other hand, packages refer to external transmissions, that is, among devices. Although primitives might cause a packet to transfer, and a received packet launches a set of primitives, they are not the same.

Basically, physic layer offers two services: Physical Data (PD) Service and Physical Layer Management Entity (PLME) Service.

There is a total of 4 types of subfunctions what a primitive can do:

Request: This primitive comes from upper layers to request the initiate the service.

Indication: This primitive goes from the physic layer to its immediately upper layer to notify important succeeded events in the physic layer. Those notifications can be caused by an internal event from the physic layer o cause the reception of a frame from another device.

Response: This primitive is originated in upper layers to physic layer and it's send to answer to some request primitive originated in the physic layer.

Confirm: Goes from the Physic layer to upper layers to answer some previous request primitive.

5.4.3.1 Data Service in the Physic Layer

Physic Layer's Data Service (referenced as PD-DATA) manages all data requests to the physic layer, from upper layers or from the network. Offers to MAC a unique primitive with 3 subfunctionalities: request, confirm and indication.

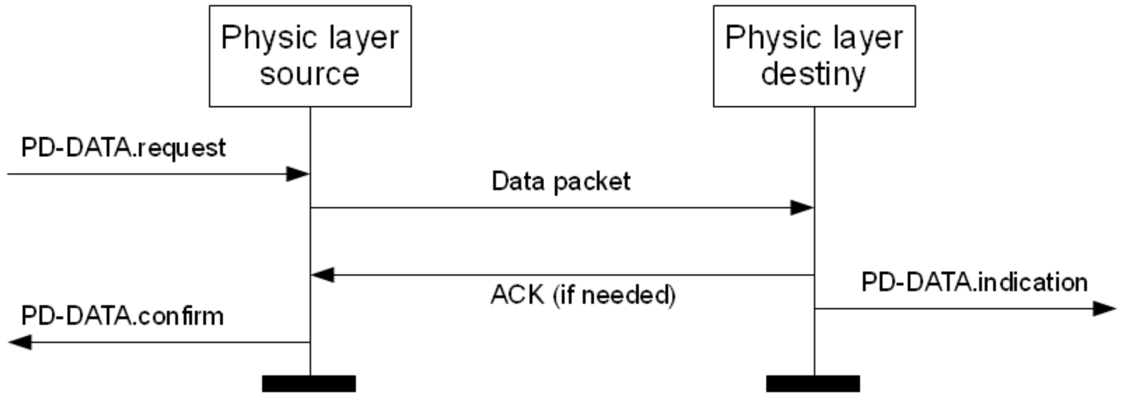

Figure 5.5: Example using physic layer's data service's primitives

Physic Layer also disposes of Management services but we are not entering in this field.

5.5 ZigBee – Bluetooth – Wi-Fi Comparative

There are a lot of wireless alternatives for designers. We will compare ZigBee with other popular standards who are also sharing unlicensed 2.4GHz band. You can see it in the table 5.16.

	ZigBee (Wireless Local Area Network (WLAN))	**Bluetooth (WLAN/WPAN)**	**Wi-Fi (WPAN)**
MAC Standard	802.15.4	802.15.1	802.11
Maximum Transmission Rate	250kbps	1Mbps	Till 54Mbps
Transmission Consumption	35 mA	40 mA	>400 mA
Standby	3μA	200μA	20mA
Memory requirement	32-60KB	>100KB	>100 KB
Network Connection Options	Mesh, point to point or point to multipoint	point to point	point to multi-point

Table 5.16: ZigBee –Bluetooth –Wi-Fi Comparative

5.5.1 Why not choose Bluetooth or Wi-Fi?

Bluetooth is a very popular wireless communication system based in the standard IEEE 802.15.1. Bluetooth works with a data transmission rate of 1Mbps. Bluetooth and ZigBee have similar power transmission, but ZigBee has a better resource, its low power in standby mode. This is because devices in Bluetooth networks have to send information to the network frequently to keep the synchronization so they can switch easily to sleep.

Wi-Fi is a network which requires almost uninterrupted activity of its devices. The advantage of this standard is the great amount of information you can send from one point to multi-point but you can see that the transmission power is also high.

From those 3 standards, only ZigBee offers the flexibility of mesh networks. ZigBee applications typically are very simple, that is why its memory requirements are also very low compared to the other two.

5.5.2 PAN: ZigBee vs Bluetooth

Carefully looking the comparative of those two standards, both of them are in the PAN category, both of them have similar radios but they are not similar at all in energy consumption. The main difference between those two standards is in its application field.

Bluetooth aims to applications with a average data transfer and uninterrupted service such as file transfer and sound transmission in communications.

ZigBee aims to applications with low data rate and low cycles of service. Devices end point do not transfer or receive information so frequently in this kind of applications and allows increase the duration of the battery.

However we can say that they are not competitive technologies yet complementary since they are two different solutions for different application fields.

We can add that Bluetooth connections among Bluetooth devices are not as flexible as ZigBee, the link is strong and static versus the flexibility of ZigBee.

Figure 5.6: ZigBee versus Bluetooth

Chapter 6

Modular Software and Wireless Devices Organization

6.1 Introduction

Software Engineering has advanced a lot in the last years. Introducing Software Engineering in programming permitted to advance to modular software.

Modular software permits to do isolated changes and introduces code reusability. Modular software also increases security, making software maintenance easy.

Some of Software characteristics are:

- Is developed, not produced
- It never spoils
- Software maintenance is more difficult than Hardware.

Software Engineering introduces the following ideas:

- Economic
- Reliable
- Efficient work
- To satisfy users requirements

6.2 Proposed system Schema

The figure 6.1 shows a general and simplified idea of the system. There are 2 types of users, a part of the HAS there is a ZigBee Network. We will see the details of each one separately.

Users can read information and change the configuration of the system. There are 2 kinds of information: Real Time Information and Stored Information. On the first one, when the users asks to the HAS the information, this sends a request to affected nodes as you can see in the figure 6.2. In the second case, is very similar but the HAS instead to send the request to the ZigBee Network, just checks the Data Base (DB).

The figure 6.3 shows the flow of the information in the ZigBee network. Basically how collected data travels from the Sensors to the HAS and this sends orders to the actuators. The information goes from bottom to top and after that goes down again.

6.3 Technical Architecture

In this part we will define the technical system and how it works.

6.3.1 Programation

The chosen environment to implement the HAS program is Java 2 Enterprise Edition. Java is a Object Oriented Programming Language, perfect for high level programming. Those properties are not exclusive of Java Platform. The main reason is because Java is very portable and architecture independent.

Java has some strong points like:

Object-Oriented Paradigm

Garbage Collection: No more stray pointers problems.

Class loading: You can dynamically deploy more code after your device has been deployed.

Robust Security Architecture: You can deploy fine-grained security control if you want. No need to re-invent your own, and risk inventing one that has security holes.

Networking: Standard Application Programming Interfaces (APIs) allow you to do networking easy.

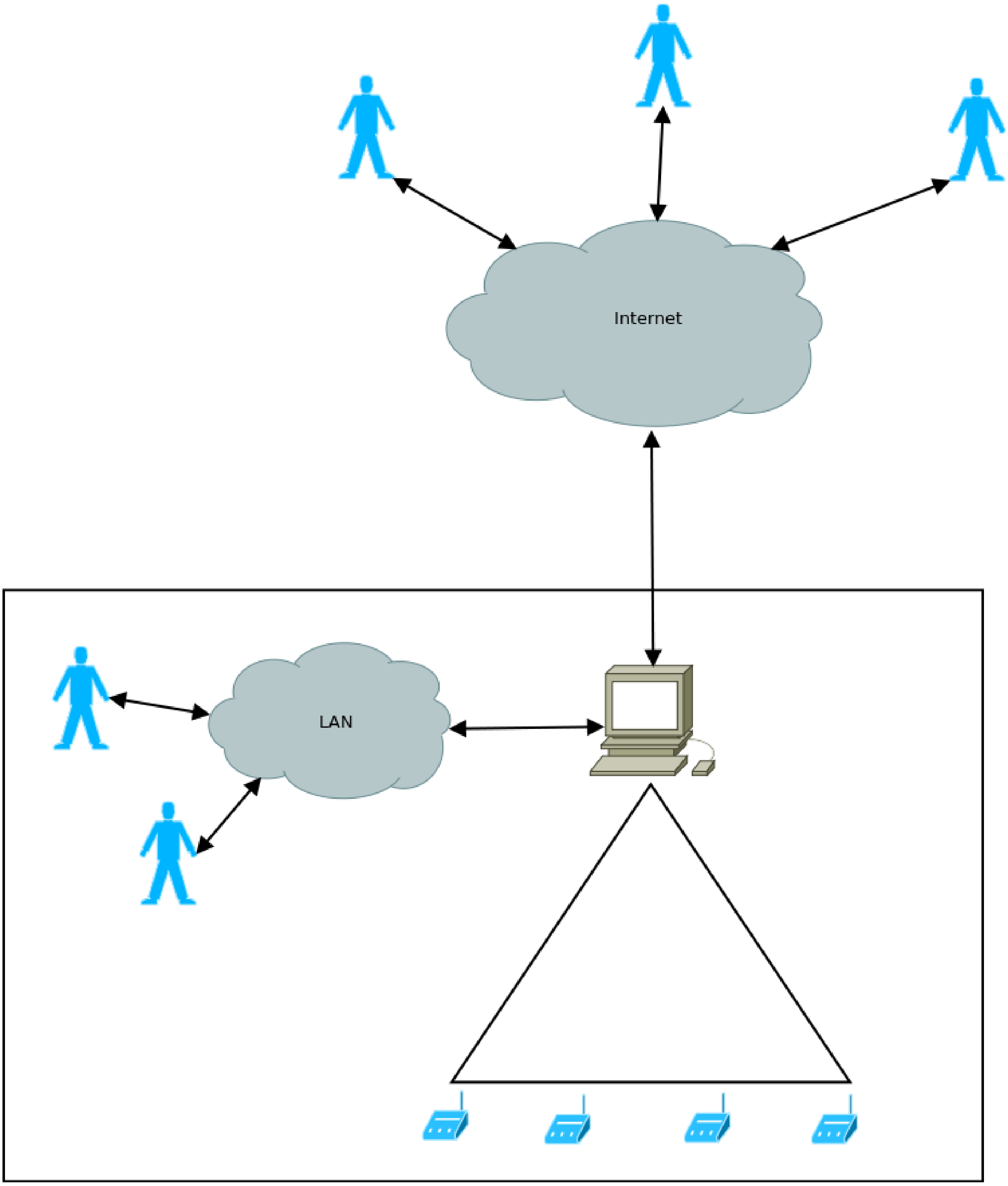

Figure 6.1: General Schema of the structure of the proposed Home Automation System

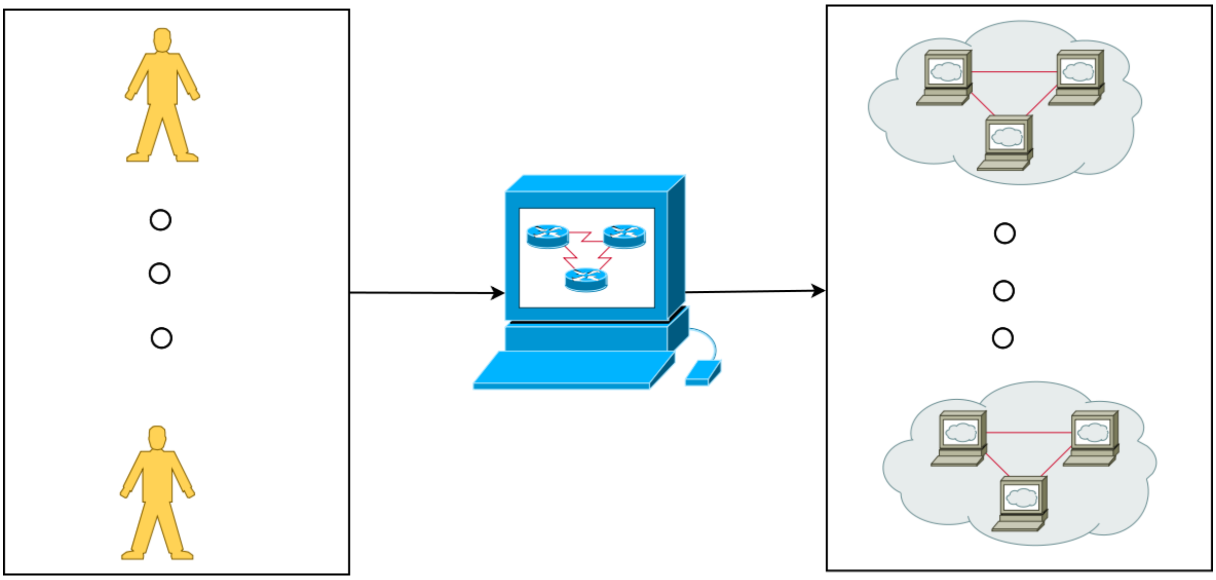

Figure 6.2: Order Flow Schema

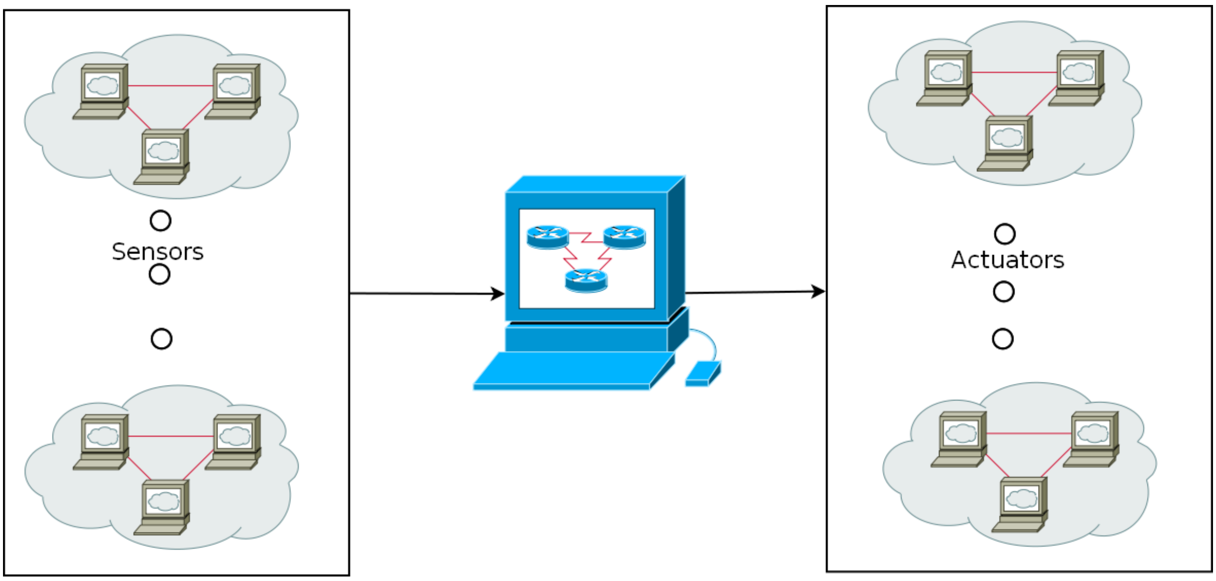

Figure 6.3: Data Flow Schema

6.3.2 Data Base

At first sign we don't need a high performance DB and all needed functionalities are basic like store and load data, creating tables and databases. Also we want to reduce economic costs so we can use MySQL[1] as our DB Software Management.

6.3.3 Operating System

Cause we chose Java as our programming language, we do not have to worry about the Operating System (OS), we have an OS independent program. Java uses a Virtual Machine called *Java Virtual Machine (JVM)* which uncouples the portability problem among OS. Every OS who can run the JVM will be able to run our program.

6.4 Proposed Basic Program

To fulfill our proposed target we will apply GRASP guidelines. GRASP is a set of patterns to answer some software problems. GRASP is a mental toolset, a learning aid to help in the design of object oriented software. Some of the main GRASP patterns are:

Expert: Information Expert is a principle used to determine where to delegate responsibilities. These responsibilities include methods, computed fields and so on.
Using the principle of Information Expert a general approach to assigning responsibilities is to look at a given responsibility, determine the information needed to fulfill it, and to determine where that information is stored.
Information Expert will lead to placing the responsibility on the class with the most information require to fulfill it.

Creator: Creation of objects in one of the most common activities in object-oriented systems. Which class is responsible for creating objects is a fundamental property of the relationship between objects of particular classes.
In general, a Class B should be responsible for creating instances of class A if one or more following rules can be applied:

- Instances of B "contains or compositely aggregates" instances of A.
- Instances of B records instances of A.
- Instances of B close uses instances of A.

[1] http://www.mysql.com

- Instances of B have the initializing information for instances of A and pass it on creation.

Controller: The Controller patter assigns the responsibility of dealing with system events to a non-User Interface class that represent the overall system or a use case scenario. A Controller Object is a non-user interface object responsible for receiving on handling a system event.
A use case controller should be used to deal with *all* system events of a use case, and may be used for more than one use case
It is defined as the first object beyond the User Interface layer that receives and coordinates ("Controls ") a system operation. The controller should delegate to other objects the work that needs to be done; it coordinates or controls the activity. It should not do much work itself.

Low coupling: is an evaluative pattern, which dictates how to assign responsibilities to support:

- Low dependency between classes
- Low impact in a class by changes in other classes
- High reuse potential

High Cohesion: Is an evaluative pattern that attempts to keep objects appropriately focused, manageable and understandable. High Cohesion is generally used to support *Low Coupling*. High Cohesion means that the responsibilities of a given element are strongly related and highly focused. Breaking programs into classes and subsystems is an example of activities that increase the cohesive properties of a system. Alternatively, low cohesion is a situation which a given element has too many unrelated responsibilities. Elements with low cohesion often suffer from being hard to comprehend, hard to reuse, hard to maintain and adverse to change.

Indirection: Supports low coupling between two elements by assigning the responsibility of mediation between them to and intermediate object. An example of this is the introduction of a controller component for mediation between data (model) and its representation (view) in the Model-View-Controller pattern.

We want to propose a modular HAS program. To achieve this goal, we propose a basic system. To build our basic system, we suggest using some design patterns to keep the system's modularity:

Model View Controller (MVC): Widely used in Internet platforms like websites. It divides the presentation Layer into 2 parts: Controller and View. The Controller receives the petition from the user and sends it to the Model. The Model processes the information and sends the answer to the View. The user can see the answer of the system through the View. Model is the equivalent of the Domain Layer of 3

Layers but in this case can be only one part of it. The Controller is the same as the one described before 6.4.

3 Layers: It divides the whole system in 3 layers: Presentation, Domain and Data. The Presentation Layer interacts with the user, sends the petition to the Domain. The Domain Layer computes the data and if have to store or load data, it asks to Data Layer. After the computations resends the information to the Presentation Layer and this one to the user. Each Layer is independent so you can modify each one per separate and the system can continue working normally. It is transparent, secure and maintainable.

Transaction: Capsules the functions in a set of listed actions. Every time you invoque an action, you are executing a transaction. It permits to increase the security and introduces atomicity in those. If you execute a transaction, if you can not execute the whole listed actions it will not change the system and make the petition persistent. It is really useful when the system fails or there are interferences.

Chain of responsibility: Is a pattern to help low Coupling. You should delegate the responsibility to do some action to the module that is closer to the one who really knows how to do it.

Facade: Provides a Unified interface to a set of interfaces in a subsystem. Fa?ade defines a high-level interface making the subsystem easy to use.

Iterator: Provides a way to access the elements of an aggregate object sequentially without exposing its underlying representation.

Observer: Defines a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.

State: Allows an object to alter its behavior when its internal state changes. The object will appear to change it class.

Strategy: Defines a family of algorithms, encapsulate each one, and make them interchangeable. Strategy lets the algorithm vary independently from clients that use it.

We have to take into account that the interface for aged people should be as easy and intuitive as it can be. To get more information you can check Interface Design for Domotic Applications in [30]

6.5 Functions

In this section we will introduce some basic functionalities of the main program due to achieve our expandable system.

6.5.1 Application Management

The system can distinguish between two type of different additions: *applications* and *modules*. Modules are destined to extend the system adding new capabilities and Applications are other programs that can interact with our system. Also modules can only work under the petition of our system and applications are autonomous, independent of our system but with the possibility of interaction.

The system have also its own *configuration*, independent of each module or application, which lets the user change the behavior of the main system such as sampling periodically, periodically saving data, where each de device belongs to, change the privileges of users or adding new users.

Also our needs can change so the program can also permit the option to *delete* installed applications and modules. Other times we just do not theed their functionality so just need to *enable* or *disable* them.

6.5.2 Data Base Management

In a first sign, we decided that it would be interesting to have a Data Base for each module, independently. This is because we want to keep low cohesion and each module is free to organize its tables on its own but keeping a basic structure similar to all modules.

In the case of applications, due to they are independent from our system, we can just store basic information like where it is, its name, its description. So we just store a *pointer* to its localization, not concerning about its internal architecture or organization.

The main system will have a Data Base with different tables to save information about Users and their privileges, installed modules (name, functionalities, with data base is, etc), installed applications (Application name, where it is and a brief description if needed), the state of the system, registered devices (to which cluster belongs, their MAC address, function, etc). There is a table for installed applications and another for modules to let the system know what it has and where they are.

6.5.3 Web Service

Our system can be accessed through Internet by remote users. Due to keep the safety of our system, we will use a web server with a Content Management System (CMS).

There are a lot of modular CMS such as Joomla[2] or Drupal[3] among others, with basic functionalities and letting to the user to choose which functionalities are needed.

6.6 Users

As mentioned before, there are 2 types of users:

Local Users

Those users can connect to the HAS directly through the Local Area Network (LAN).

Remote Users

Those users can connect to the HAS using Internet access. In general their functions are limited compared to local users, basically their main operations are read operations. Even in Remote Users, there are different kinds: Those who can only read and those who can modify the configuration. Basically depends on the functionality. Those who can only read are external services and those who can modify are relatives of the user.

6.7 ZigBee Network

ZigBee specification have been widely explained in the chapter 5. After all the explanation, the most important is how to organize the devices network. ZigBee offers 3 types of Topology: *Star topology* in this case is almost useless in case of big surfaces because consumed energy increases exponentially in far devices. *Mesh topology* can be deployed in this kind of scenario and *tree topology* can also be deployed.

6.7.1 Topology

Depending on the topology, the organization of the network can be easy or difficult; also energy consumption can change a lot.

We decided to use a Cluster Tree Topology. This topology is equivalent to the native ZigBee's Tree Topology with clusters and each device belongs to a only one cluster.

[2] http://www.joomla.org
[3] http://www.drupal.org

There is a Network Coordinator (our HAS), some Cluster Heads (FFD devices) and Routers (FFD devices) and Terminal Nodes (RFD devices).

The number of Cluster Heads depends on how many clusters we want to have. Here we found a big problem. What is better? Making different clusters depending of the kind of devices such as a cluster for light sensors, one for temperature sensors, one for switch actuators... or mixing each one and in result, having heterogeneous clusters? We prioritized the energy consumption instead of simply network management and we decided that heterogeneous clusters are preferred.

In Tree Topology, the information flows from bottom to top and the orders goes from top to bottom. The cost in time is $\Theta(\log n)$ where n is the number of devices. We arrived to this conclusion following the next reasoning.

1. We will consider the total number of devices as

$$\boxed{n}$$

2. We will consider the transmission time of each device as

$$\boxed{delay_i, 0 \leq i \leq n}$$

3. In a lineal topology, to go from the first node to the last one will cost

$$\boxed{\Theta(\sum_{i=1}^{n} delay_i)}$$

4. The first think we need to know about trees is that their height is

$$\boxed{\Theta(\log n)}$$

5. We can define $delay_{max}$ as the time of the slowest device, simplify the formula of 3 as

$$\boxed{O(n \times delay_{max}) = \sum_{i=1}^{n} delay_i}$$

6. We can adapt the time to tree topology and we will have

$$\boxed{\Theta(\log(n \times delay_{max}))}$$

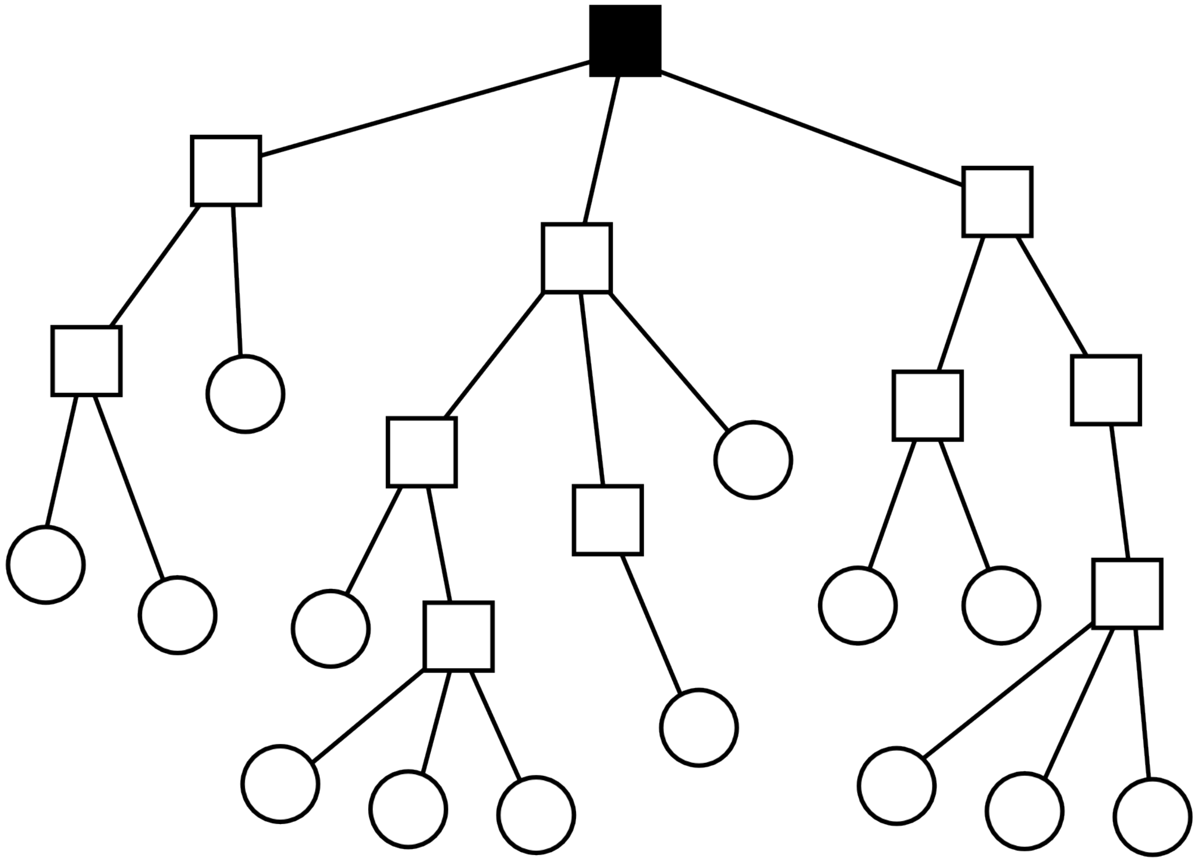

Figure 6.4: Example of Cluster Tree Topology where the black square is the Network Coordinator and the first level of squares are cluster heads and under those there are router and terminal nodes

7. For huge values of n despise the value of delay (also because is a constant). That is why we can conclude as

$$\boxed{\Theta(\log(n))}$$

To implement this topology we can use implementation proposals such those mentioned in [22], [23] or [24].

6.7.2 justification of the decisions

The reason to choose ZigBee is obviously because it fulfills our requirements and it is cheap.

We have chosen clustered-tree cause it is easy to implement, easy to manage and the consumption is lower than mesh topologies. The energy efficiency and other advantages are widely explained in [13]

The path took by a message in Cluster Tree topology would be longer than a Mesh Topology or Star Topology but the cost of maintenance is much lower and due to the low rate network, and the complexity of network management is also lower.

Chapter 7

Conclusion

The populations gradually aging problem is something we can not solve but we can help to make it more comfortable. There are also many on-going research such as [31], [32] or [33] as well as active projects such as Mercury [28] that can be used for introducing aging people to wearable sensors.

Home Automation Systems are more and more popular making people's life easier but it is still very limited in functionalities. There are HAS projects like Casas[27] which collects data to make a big DB to achieve a Expert System[37].

There are a lot of similar works making this research field a hot spot. Looking for low cost Home Automation Devices such as mentioned in [14]

We can conclude that there is an effort to make HAS something common and affordable just like computers and television progressed over the centuries.

To make a robust HAS software still requires a lot of work and it can not be done by few people. The same way that modular software is made to big companies to do different tasks can be applied in this platform.

On Wireless Devices, technology is advancing in lighting speed and it is not difficult to say that in the future they will be smaller, faster with low energy consumption but without a good management system it is completely useless. In this case, a Tree-type topology is the best choice but in other fields like multimedia a peer-to-peer topology would be more efficient and will offer better QoS.

Future work related with this thesis may be a real implementation of a modular HAS using patterns described in 6.4

Appendix A

A Brief Explanation of DSSS

Direct Sequence Spread Spectrum (DSSS) is a transmission mode where the transmitted signal deals with a wider bandwidth than really needed. Due to achieve this spectrum expansion, an independent code sequence of the information signal is used.

The idea is to transmit all the sequence of the code in the same time we use to transmit a bit of information. If the bit of information was a logic "1"a sequence of code without changes will be transmitted, if it is a logic ''0"a reverse sequence of code will be transmitted. In resume, we can affirm that it is a XOR operation between the information and the code synchronized to the speed of the code.

The fact to transmit a whole sequence of bits in the time of one only bit provokes a spectral expansion. Some examples are show in figure A.1 and figure A.2

A T_c (Chip Time) is defined as the needed time to transmit a bit of code. Then, $T_s = N \times T_c$ and N-chips are transmitted per symbol. Have to take into account that N is a natural number.

One of the main features of this transmission mode is that each user has a unique code that is orthogonal with all other codes. Because the number of orthogonal codes among each other is limited, pseudo-random codes are used such as *Gold*,*Barker*, *Sequence M*, etc. which can guarantee the code orthogonality in a high percent, achieving a high number of available orthogonal codes (and increase the number of users) keeping a correct duty of the system

Those codes are used because in case of 2 users transmits at the same time, the receiver will receive the addition of both transmissions. Due to undo the expansion the orthogonality is needed.

To decode, the receiver multiplies the received sequence with the code of one of the

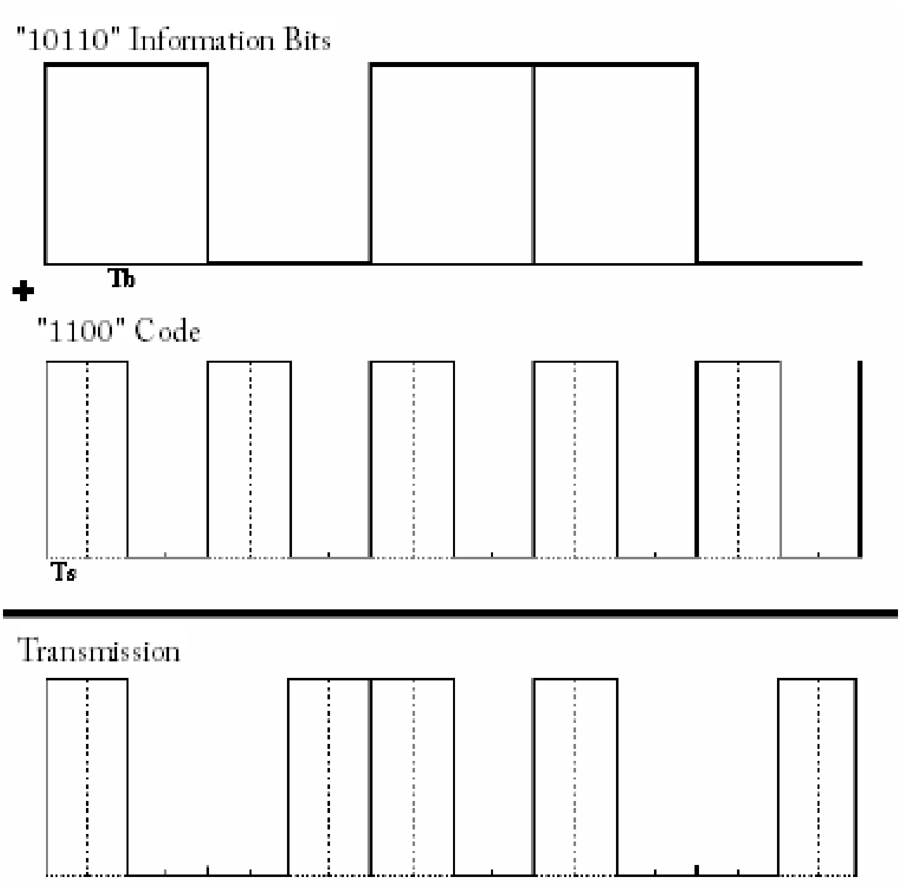

Figure A.1: First example of sequence of chips

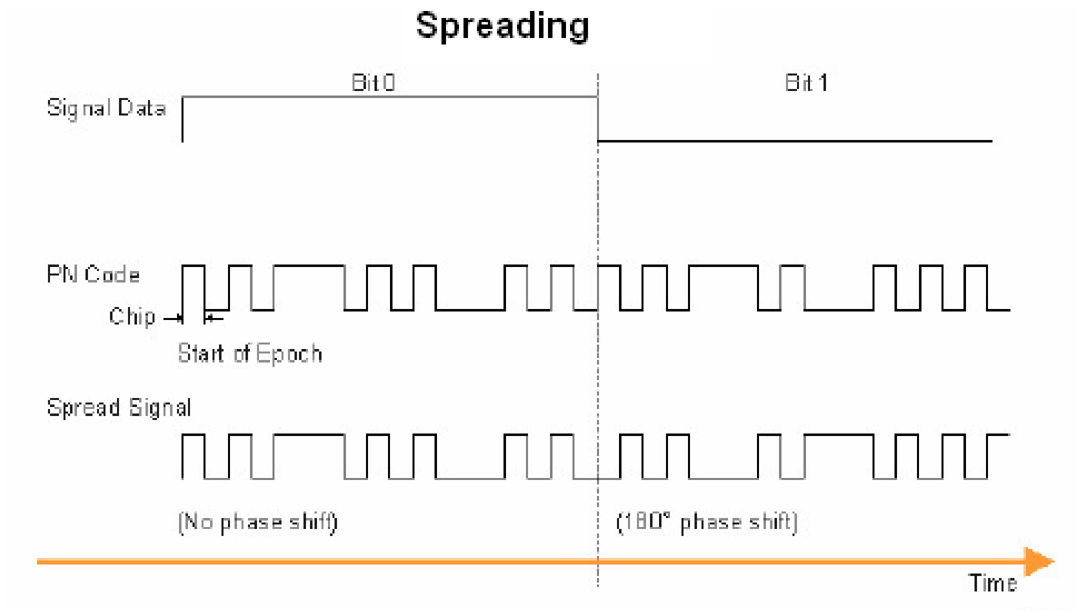

Figure A.2: Second example of sequence of chips

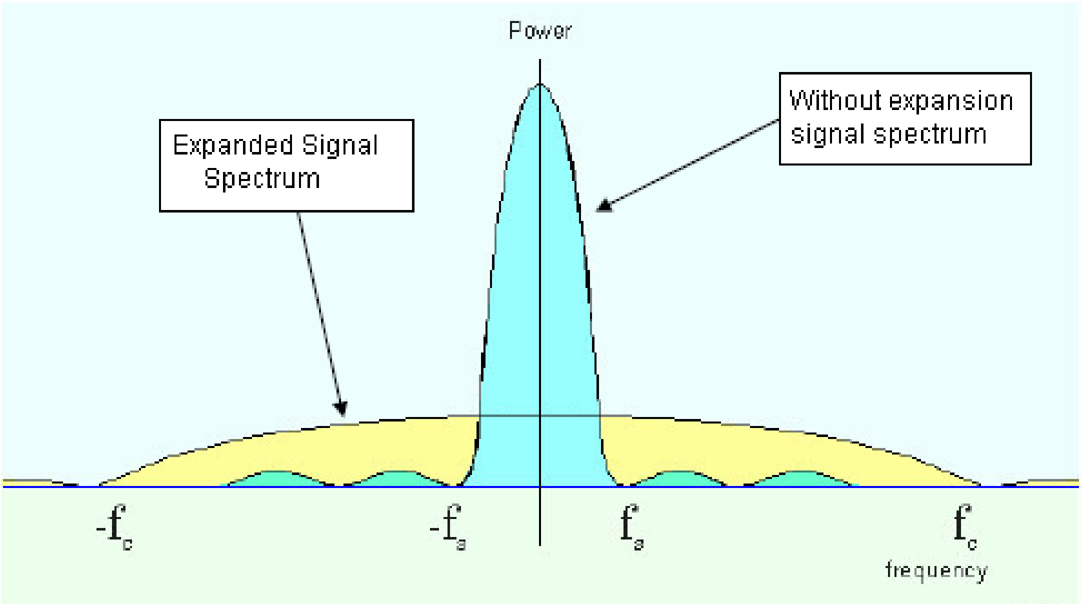

Figure A.3: Spectrum comparation

nodes, chip by chip with each active user. The result is integrate all received chips . . . (in other words, add all received chips) and the result will be the sequence of bits of the original information.

Obviously the system requires a perfect temporal synchronization between sender and receiver, in addition also requires a perfect power control because in case of multiple-senders, the receiver will receive the addition of both codes.

Spectrally, once expanded, the spectrum is so wide and the power is distributed in so many frequencies that a signal without expansion would be just noise.

In conclusion, the advantages to use this system are the high interference protection that offers and the fact that several users can share the same frequency band and can transmit at the same time (without dividing the spectrum either temporal access). On the other hand, the strict synchronism and the power control are needed, also the fact that a wider band is needed

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