VIETNAM NATIONAL UNIVERSITY, HANOI
UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Doan Ba Cuong

INDOOR AIR QUALITY MONITORING FOR SMART BUILDING

Major: Electronics and Communications

Hanoi - 2016

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Supervisor: Assoc. Prof. Dr. Tran Duc Tan

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AUTHORSHIP

I hereby declare that the work contained in this thesis is of my own and has not been previously submitted for a degree or diploma at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no materials previously or written by another person except where due reference or acknowledgement is made.

Signature: ....

SUPERVISOR'S APPROVAL

I hereby approve that the thesis in its current form is ready for committee examination as a requirement for the Bachelor of Electronics and Communications degree at the University of Engineering and Technology.

Signature: ....

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Doan Ba Cuong

ABSTRACT

Nowadays, many developing countries are suffering from air pollution, especially buildings in the big cities. While quite a few air quality monitoring devices have been built by governments in buildings. However, the quality of indoor air inside offices, schools, and other workplaces is important not only for workers' comfort but also for their health. Poor indoor air quality (IAQ) has been tied to symptoms like headaches, fatigue, trouble concentrating, and irritation of the eyes, nose, throat and lungs. Also, some specific diseases have been linked to specific air contaminants or indoor environments, like asthma with damp indoor environments. So, this thesis research on a system to monitor the poison gas in citizen in order to warn and protect human health. The system is a local network and nodes send the data to the gateway. People can access the data from anywhere, anytime with only your smart phone, computer (any devices can connect to the Internet) and the Internet.

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ABBREVATIONS

ADC	Analog to Digital Converter
CPU	Central Processing Unit
DIP	Dual In-line Package
DSP	Digital Signal Processing
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPI	Environmental Performance Index
FET	Faculty of Electronics and Telecommunications
GPS	Global Positioning System
GPRS/3G	General Packet Radio Service/Third Generation
I2C	Inter-Integrated Circuit
IAQ	Indoor Air Quality
IEEE	Institute of Electrical and Electronics Engineers
LPG	Liquefied Petroleum Gas
MAC	Medium Access Control
MANET	Mobile Adhoc Netwok
MEMS	Micro-Electro-Mechanical Systems
PAN ID	Personal Area Network Identifier
PPM	Parts Per Million
PWM	Pulse Width Modulation
RH	Relative Humidity
RTC	Real Time clock

SMD	Surface-Mount Packages
SPI	Serial Peripheral Interface Bus
SRAM	Static Random-Access Memory
WSN	Wireless Sensor Network
VNU	Viet Nam National University
UET	University of Engineering and technology
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus

Chapter 1

INTRODUCTION

1.1 Motivation

Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. Understanding, controlling common pollutants indoors and monitoring poison gas level can help reduce your risk of indoor health concerns and improve the quality of life.

Nowadays, the environment has been contaminated. Pollution is a big problem in any country. The environmental pollution is alarming in Vietnam. "Vietnam is ranked 79th the lower part in the middle group. But on specific detailed criteria, Vietnam displayed even worse performance, including air quality with effects on human health, water, and environmental burden of disease". Air quality in Vietnam is lagging among the ten worst nations in the world, ranking 123rd, and it is forecast that air pollution will continue to worsen in the near future and may fall to 125th place, according to the EPI survey. This information, while alarming, is now new, as independent surveys by Vietnamese agencies have reached the conclusion that the country's air pollution has worsened at a steady rate and has reached an alarming level, said Ph.D. Ngo Duc The – a Vietnamese professor of the National University of Singapore. Smoke and dust created by trucks are the main factors leading to the decline in air quality in Vietnam, especially in major cities like Hanoi and Ho Chi Minh City[1].

In our lifetime, we each spend tens of thousands of hours at work. Poor quality indoor air can cause major health problems, such as allergies and respiratory diseases. And even the minor ailments, such as headaches and eye irritation, can cause discomfort and distraction that can ultimately lead to lower productivity. In additions, a lot of people live in apartment in buildings with poor air conditional. Moreover, patients in a hospital breath in poor air quality without knowing that, students studies while poison gas around them in school and some similarly case.

People need a system to control air condition to protect health's citizen, the system in this thesis can help you with innovative solutions to suit your workplaces and buildings.

1.2 Contributions and thesis overview

The system in this thesis is intended to help people who work, live, study in office buildings to monitoring the poison gas that including some common gases such as LPG, CO, CO2, Alcohol, Smoke, Propane, CH4 and warning when the level of poison gas exceed the allowed threshold in order to maintaining a good indoor environment and reduce the risk for our's health. However, good indoor air quality also depends on the actions of everyone in the building, a partnership between building management and occupants is the best way to maintain a healthy and productive work space.

The system using some devices to create a local network by using Zigbee communications. In other way, this system called wireless sensor network (WSN). At each node(device), the raw data read from Gas sensor(MQ-2) will be calibrated depend on temperature and humidity. After that, the data will be send to the gateway to analyze and processing. Lastly, level of poison gas will be send to the Internet. Therefore, people can be accessed them anytime, anywhere from the Internet.

The rest of this thesis is organized as follows.

Chapter 2 provides theoretical background, focusing on application poison gas monitoring system and architecture of WSN.
In Chapter 3, Explains the the proposed method to design and set up the integrate system.
In Chapter 4, Some experimental results with real dataset and discussion.
In Chapter 5, Conclusions and directions for future work.

Chapter 2

SYSTEM INTEGRATION

2.1 Components

2.1.1 Waspmote

a, Waspmote Introduction

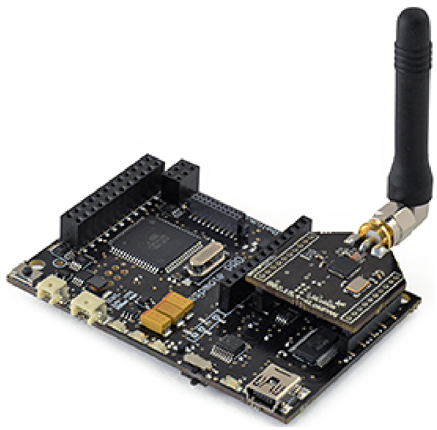

Figure 2.1: Kit Waspmote

Waspmote is the brand name of a modular platform created by Libelium and used in Wireless Sensor Networks (WSN). A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively compute their data through the network. The WSN is built of nodes, in this case each node is a Waspmote module. The idea of a modular architecture is to integrate only the modules needed in each device. Modules can be changed and expanded depending on the needs, this is the strong point of the platform.

b, Specifications.

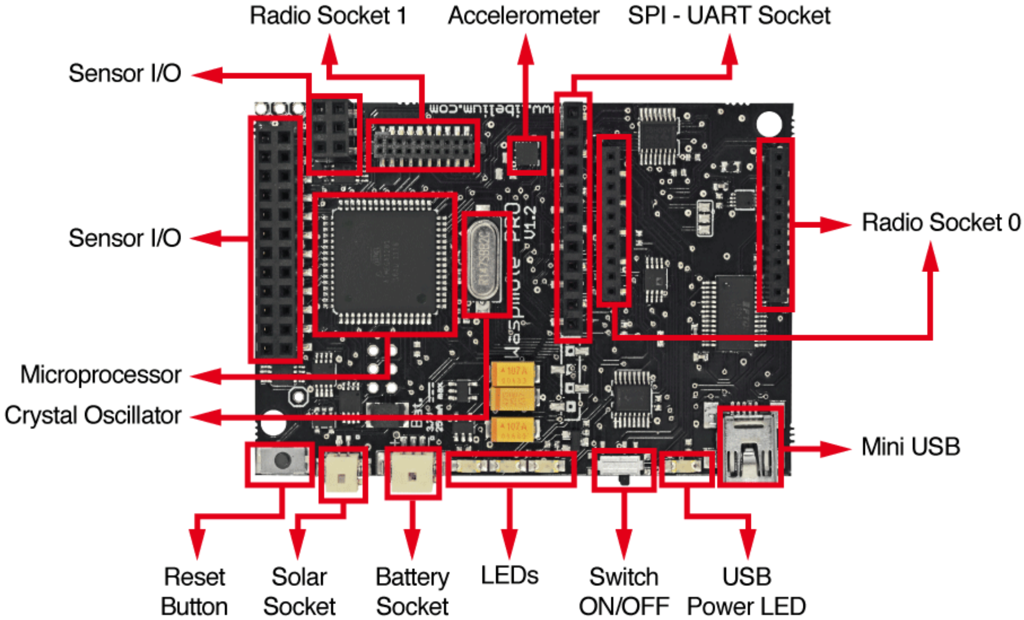

Figure 2.2: Details Kit Waspmote

Table 2.1: Table of Waspmote specifications

General data:		**Consumption:**	
Microcontroller:	ATmega1281	ON:	15 mA
Frequency:	14.7456 MHz	Sleep:	55 µm
SRAM:	8 KB	Deep Sleep:	55 µm
EEPROM:	4 KB	Hibernate:	0.07 µm
FLASH:	128 KB	Operation without recharging:	1 year *
SD Card:	2 GB	**Battery voltage:**	3.3 V - 4.2V
Weight:	20 gr	**Solar panel charging:**	6 - 12V -280mA
Dimensions:	73.5 x 51 x 13 mm	**USB charging:**	5 V - 100mA
Temperature Range:	[-10 °C, +65°C]		
Clock:	RTC (32KHz)		

c, Built-in sensors on the board.

- Temperature (±): -40°C , +85°C. Accuracy: 0.25°C
- Accelerometer: ±2g/±4g/±8g

d, Inputs/Outputs.

- 7 Analog (I), 8 Digital (I/O), 1 PWM, 2 UART, 1 I2C, 1 USB, 1 SPI.

e, Block Diagram.

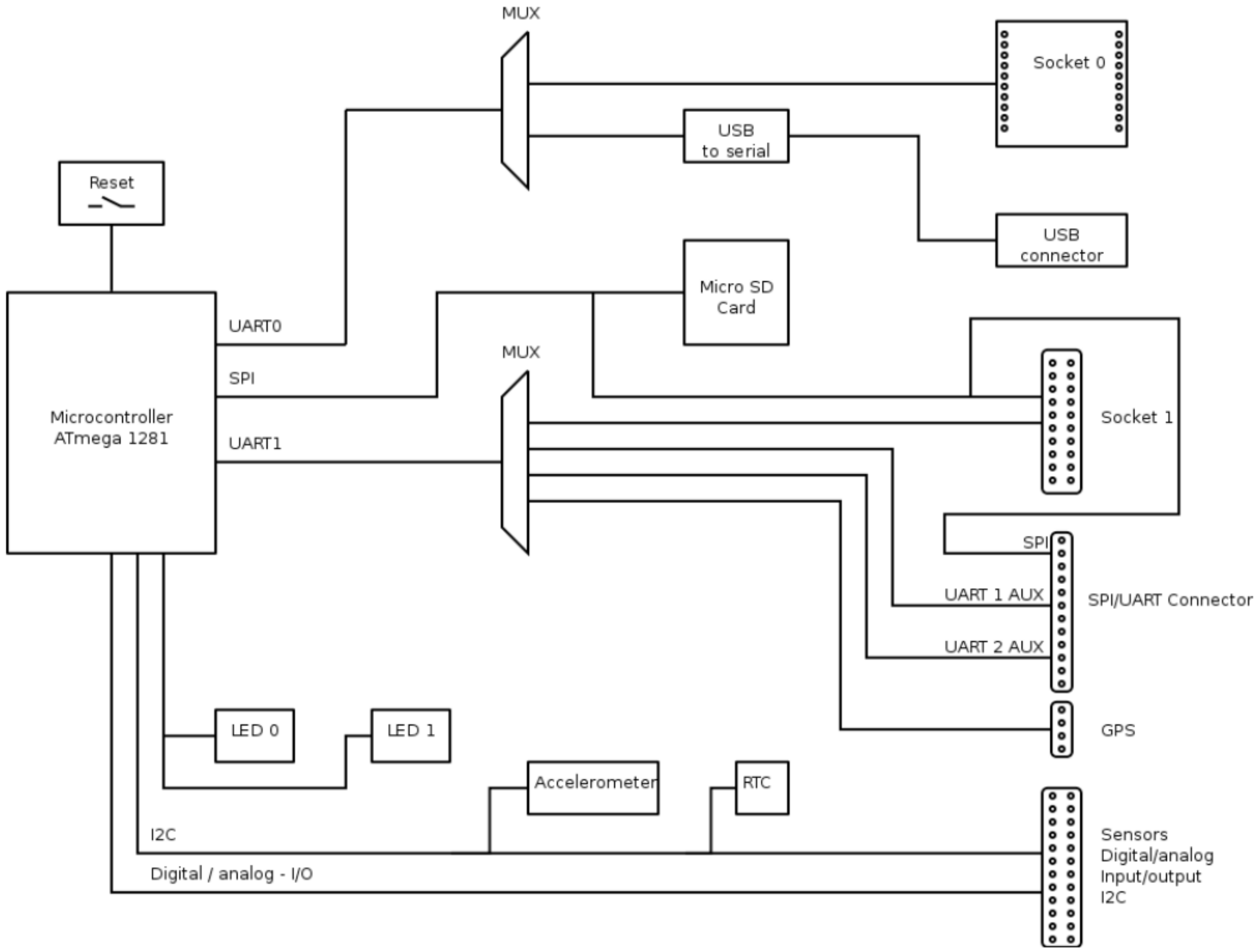

Figure 2.3: Waspmote block diagrams – Data signals

The XBee module, the ICSP connector and USB connector share the same UART, so these modules can't work simultaneously. This feature creates most of the problems communicating with the board. However, we can obtain the expansion radio board and connect the XBee module in UART1.

The other microcontroller UART is connected to a four channel multiplexer, and it is possible to select in the same program which of the four new channels is required to connect to the UART on the microcontroller. These channels are connected as follows. One is connected to the GPRS/3G board, the other to the GPS and the other two are accessible to the user in the auxiliary I2C – UART connector.

The I2C communication bus is also used in Waspmote where three devices are connected in parallel: the accelerometer, the RTC and the digital potentiometer (digipot) which configures the low battery alarm threshold level. In all cases, the microcontroller acts as master while the other devices connected to the bus are slaves. The SPI port on

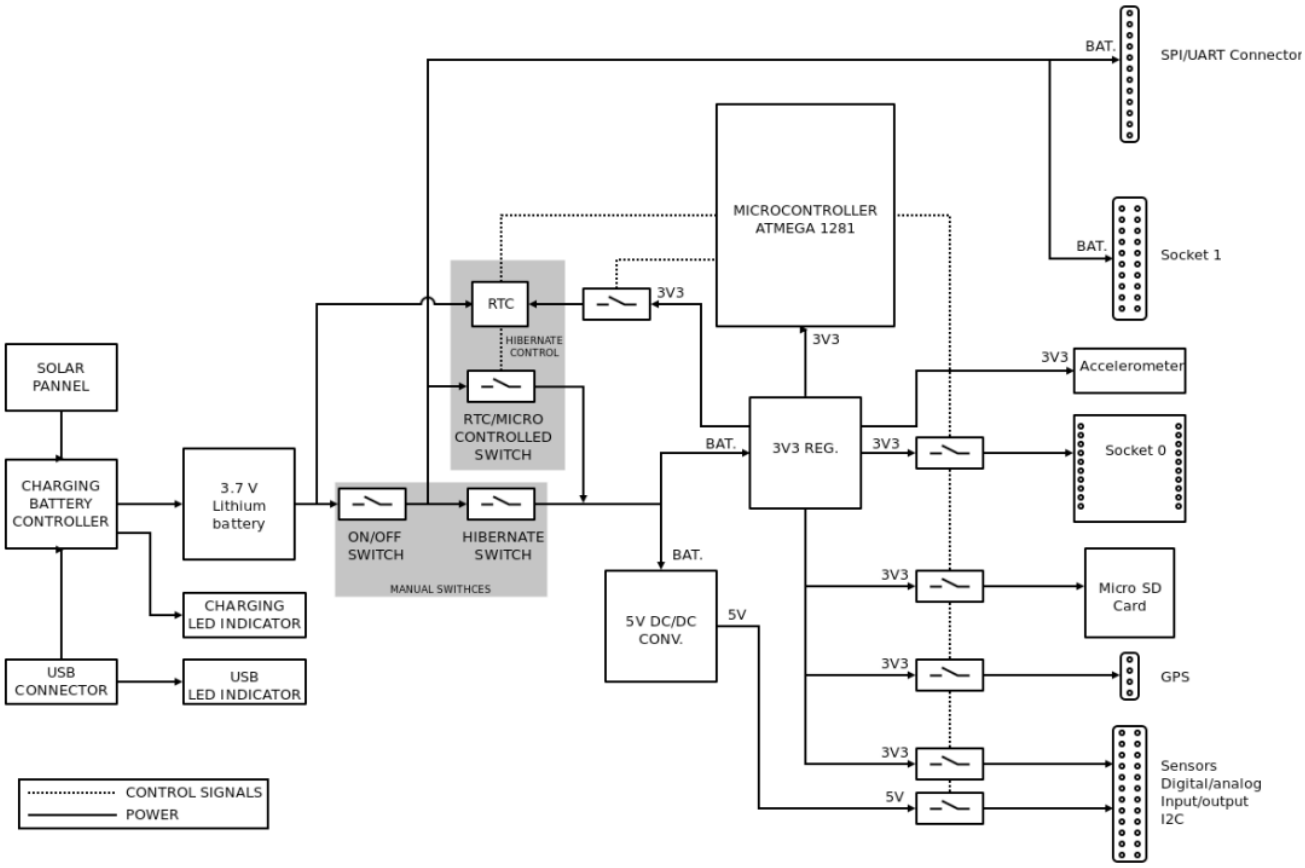

Figure 2.4: Waspmote block diagrams – Power signals

2.1.2 Module Xbee

The XBee Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices.

Figure 2.5: Module Xbee

2.1.3 Waspmote Prototyping Board 2.0

The Waspmote Prototyping Board 2.0 has been designed to make it as easy as possible for the user to integrate any type of sensor. With this aim in mind, the board has been endowed with a 16 bit analog-digital converter (ADC) which provides up to a 68uV resolution in a 0 to 4.5V range for a differential input; an area of independent pads where pins, cables, passives or DIP encapsulated integrated circuits can be welded; and an area for SMD encapsulated integrated circuits upon which various circuits or sockets with different sizes can be mounted.

Electrical Characteristics

Operating ratings:

- Board supply voltages: 3.3V and 5V
- Analog-to-Digital converter supply voltage: 5V
- Maximum admitted current (continuous): 200mA
- Maximum admitted current (peak): 400mA

Absolute maximum ratings:

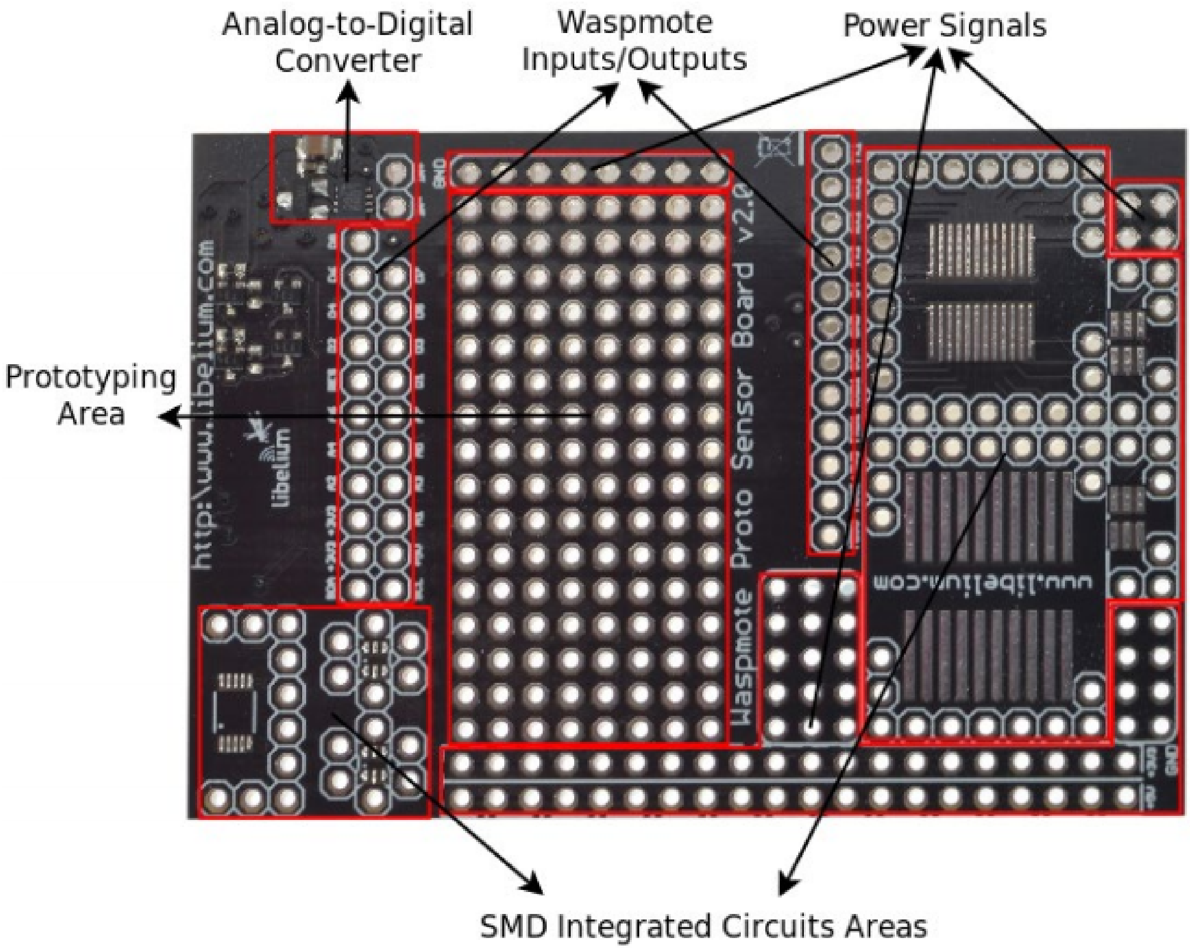

Figure 2.6: Prototype V2.0

- Microprocessor pin voltage: -0.5V to 3.8V
- Analog-to-Digital converter input voltage: -0.3V to 5.3V
- Microprocessor pin current: 40mA

2.1.4 Gas Sensor(MQ-2)

Sensitive material of MQ-2 gas sensor is SnO_2, which with lower conductivity in clean air. When the target combustible gas exist, The sensor's conductivity is more higher along with the gas concentration rising. Please use simple electrocircuit, Convert change of conductivity to correspond output signal of gas concentration.MQ-2 gas sensor has high sensitivity to LPG, Propane and Hydrogen, also could be used to Methane and

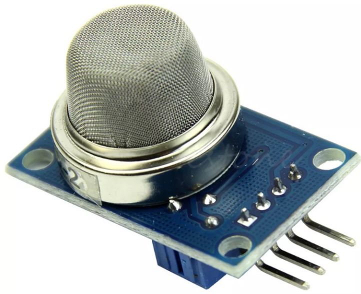

Figure 2.7: Gas sensor MQ-2

other combustible steam, it is with low cost and suitable for different application.

a, Characteristic.

- Good sensitivity to Combustible gas in wide range
- High sensitivity to LPG, Propane and Hydrogen
- Long life and low cost
- Simple drive circuit

b, Application.

- Domestic gas leakage detector
- Industrial Combustible gas detector
- Portable gas detector

c, Sensitivity characteristics.

The typical sensitivity characteristics of the MQ-2, ordinate means resistance ratio of the sensor (Rs/Ro), abscissa is concentration of gases. Rs means resistance in different gases, Ro means resistance of sensor in 1000ppm Hyrogen. All test are under standard test conditions.

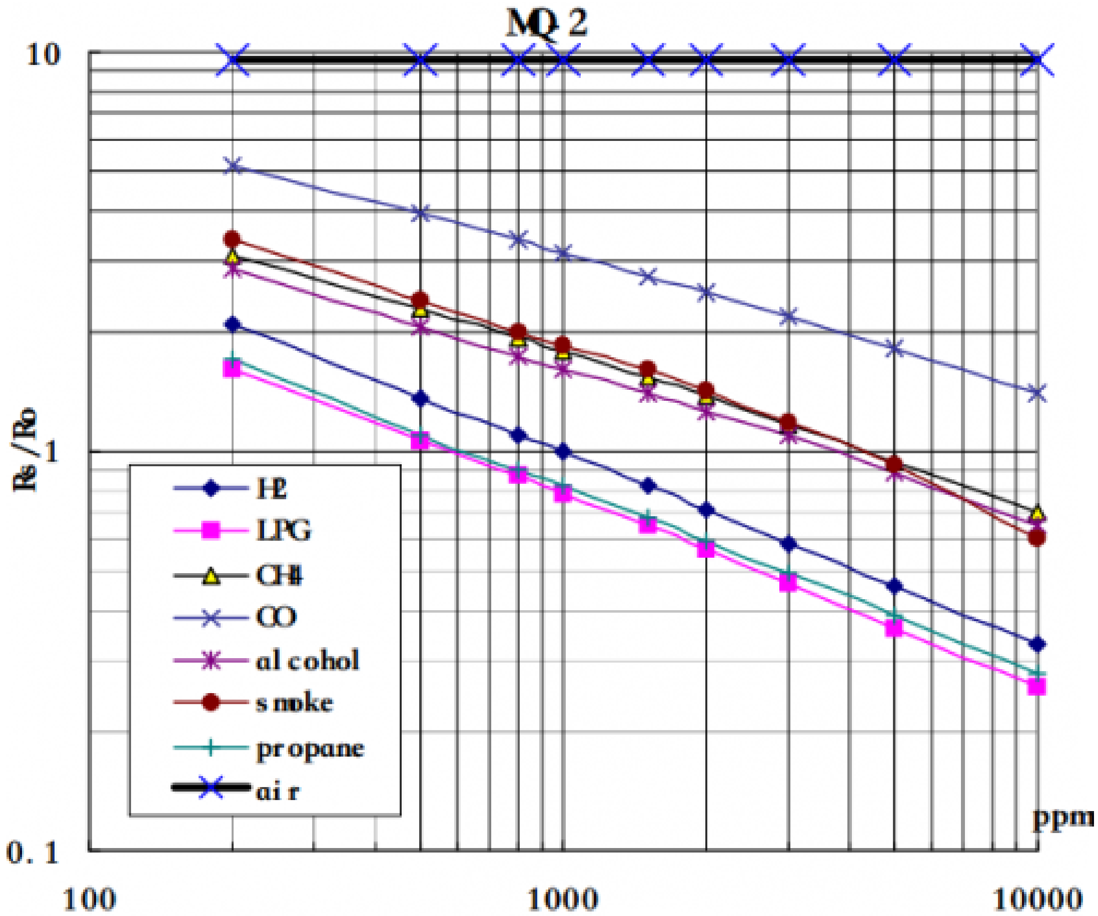

Figure 2.8: MQ-2 Sensitivity Characteristics

d, Influence of Temperature/Humidity.

The typical temperature and humidity characteristics. Ordinate means resistance ratio of the sensor (Rs/Ro), Rs means resistance of sensor in 1000ppm Butane under different temperature and humidity. Ro means resistance of the sensor in environment of 1000ppm Methane, 20°C/65%RH.

Sensitivity Adjustment

Resistance value of MQ-2 is difference to various kinds and various concentration gases. So,When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm liquified petroleum gas - LPG,or 1000ppm iso-butane (i-C4H10) concentration in air and use value of Load resistance that(RL) about 20 KΩ (5KΩ to 47 KΩ). When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

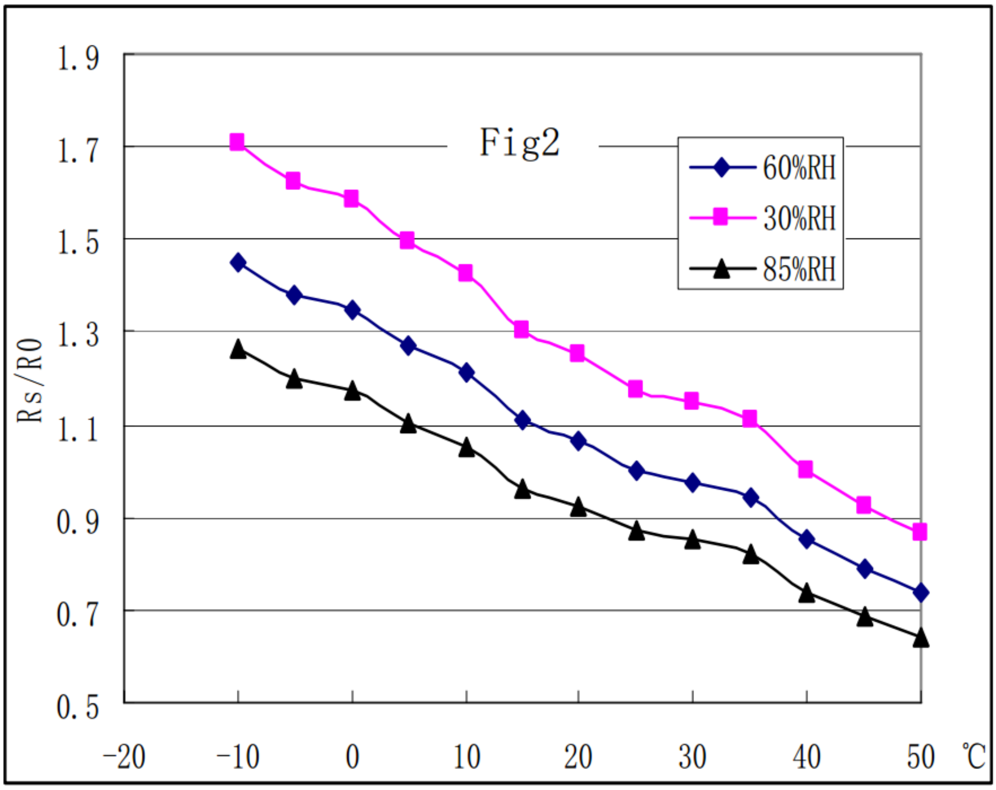

Figure 2.9: Influence of Temperature/Humidity

2.1.5 Gateway Module(Coordinator)

Figure 2.10: Gateway Module

Each ZigBee network must have one coordinator. A coordinator has the following characteristics:

- It selects the channel and PAN ID (both 64-bit and 16-bit) to start the network

- It can allow routers and end devices to join the network
- It can assist in routing data
- It can not sleep. It has to be always awake

2.1.6 Power Management

Figure 2.11: Battery

Feature

- High energy density
- Excellent safety performance
- Excellent storage performance and low self-discharge rate
- Wide temperature range, operation from: -20°C ~ +60°C
- Environmentally

2.2 Wireless Sensor Network(WSN)

2.2.1 Introduction

A wireless sensor network is a collection of nodes organized into a cooperative network. Each node consists of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single omnidirectional antenna), have a power source (e.g., batteries and solar cells), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Systems of 1000s or even 10,000 nodes are anticipated. Such systems can revolutionize the way we live and work[2].

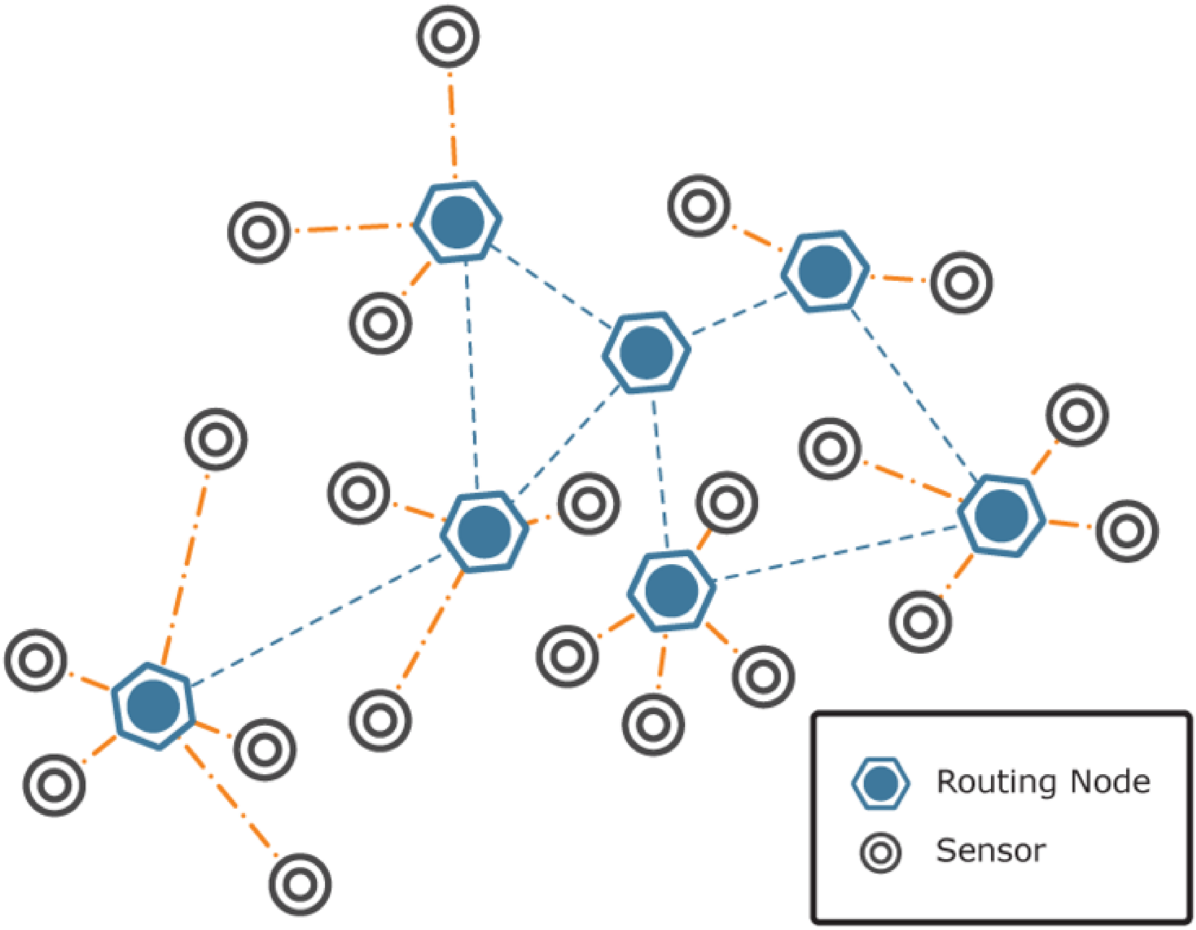

Figure 2.12: Wireless Sensor Network

Design challenges encountered in building wireless sensor networks may be categorized under three classes: hardware design, wireless networking, and applications.

- **Hardware**
  - This category includes the entire range of design activities related to the hardware platforms that comprise sensor networks. MEMS sensor technology is an important aspect of this category.
  - Digital circuit design and system integration for low power consumption is also in this category as well as design of a low power sophisticated RF front end and associated control circuitry.
- **Wireless Networking**
  - Given the hardware limitations and physical environment in which the nodes must operate, along with applications level requirements the algorithms and protocols must be designed to provide a robust and energy efficient communications mechanism. Design of physical layer methods such as modulation and source and channel coding also fall in this category. Channel access methods must be devised and routing issues and mobility management must be solved.
- **Applications**
  - At the application layer, processes aim to create effective new capabilities for efficient extraction,manipulation, transport and representation of information derived from sensor data. In most applications, sensor networks have various functional components: detection and data collection, signal processing, data fusion, and notification.

In WSNs, the sensor nodes have the dual functionality of being both data originators and data routers. Hence, communication is performed for two reasons:

- Source function: Source nodes with event information perform communication functionalities in order to transmit their packets to the sink.

- Router function: Sensor nodes also participate in forwarding the packets received from other nodes to the next destination in the multi-hop path to the sink[3].

2.2.2 WSN Routing

Multihop routing is a critical service required for WSN. Because of this, there has been a large amount of work on this topic. Internet and MANET routing techniques do not perform well in WSN. Internet routing assumes highly reliable wired connections so packet errors are rare; this is not true in WSN. Many MANET routing solutions depend on symmetric links (i.e., if node A can reliably reach node B, then B can reach A) between neighbors; this is too often not true for WSN. These differences have necessitated the invention and deployment of new solutions[4].

There are some important keys issues for WSN routing:

- Reliability: Since messages travel multiple hops it is important to have a high reliability on each link, otherwise the probability of a message transiting the entire network would be unacceptably low. Significant work is being done to identify reliable links using metrics such as received signal strength, link quality index which is based on "errors," and packet delivery ratio. Significant empirical evidence indicates that packet delivery ratio is the best metric, but it can be expensive to collect.

- Integration with wake/sleep schedules: To save power many WSN place nodes into sleep states. Obviously, an awake node should not choose an asleep node as the next hop (unless it first awakens that node).

- Unicast, multicast and anycast semantics: First, the message may also include an ID with a specific unicast node in this area as the target, or the semantics may be that a single node closest to the geographic destination is to be the unicast node. Second, the semantics could be that all nodes within some area around the destination address should receive the message. This is an area multicast. Third, it may only be necessary for any node, called anycast, in the destination area to receive the message.

- Real-Time: For some applications, messages must arrive at a destination by a deadline. Due to the high degree of uncertainty in WSN it is difficult to develop routing algorithms with any guarantees.

- Mobility: Routing is complicated if either the message source or destination or both are moving. Solutions include continuously updating local neighbor tables or identifying proxy nodes which are responsible for keeping track of where nodes are. Proxy nodes for a given node may also change as a node moves further and further away from its original location.

- Security: If adversaries exist, they can perpetrate a wide variety of attacks on the routing algorithm including selective forwarding, black hole, Sybil, replays, wormhole and denial of service attacks.

- Congestion: Today, many WSN have periodic or infrequent traffic. Congestion does not seem to be a big problem for such networks. However, congestion is a problem for more demanding WSN and is expected to be a more prominent issue with larger systems that might process audio, video and have multiple base stations (creating more cross traffic).

2.2.3 Node Feature

a, Coordinator

This device allows to collect data which flows through the sensor network into a PC or device with a standard USB port. Waspmote Gateway will act as a **"data bridge or access point"** between the sensor network and the receiving equipment. This receiving equipment will be responsible for storing and using the data received depending on the specific needs of the application.

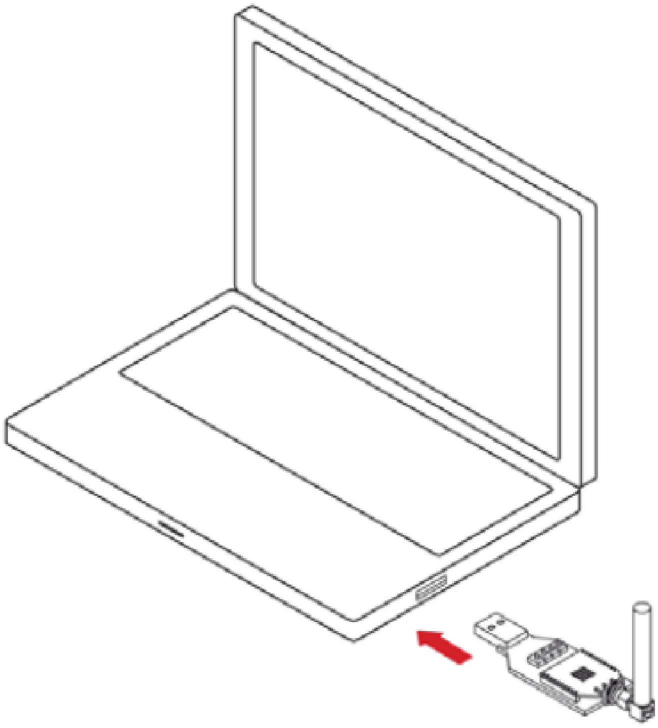

Figure 2.13: Waspmote Gateway connected in a PC

a, LEDs

Four indicator LEDs are included in the Gateway:

- USB power LED: indicates that the board is powered through the USB port

- X LED: indicates that the board is receiving data from the USB port.
- TX LED: Indicates that the board is sending data to the USB port
- I/O 5 configurable LED: associate

The configurable LED connected to the XBee's I/O 5 pin can be configured either as the XBee's digital output or as the XBee's indicator of association to the sensor network.

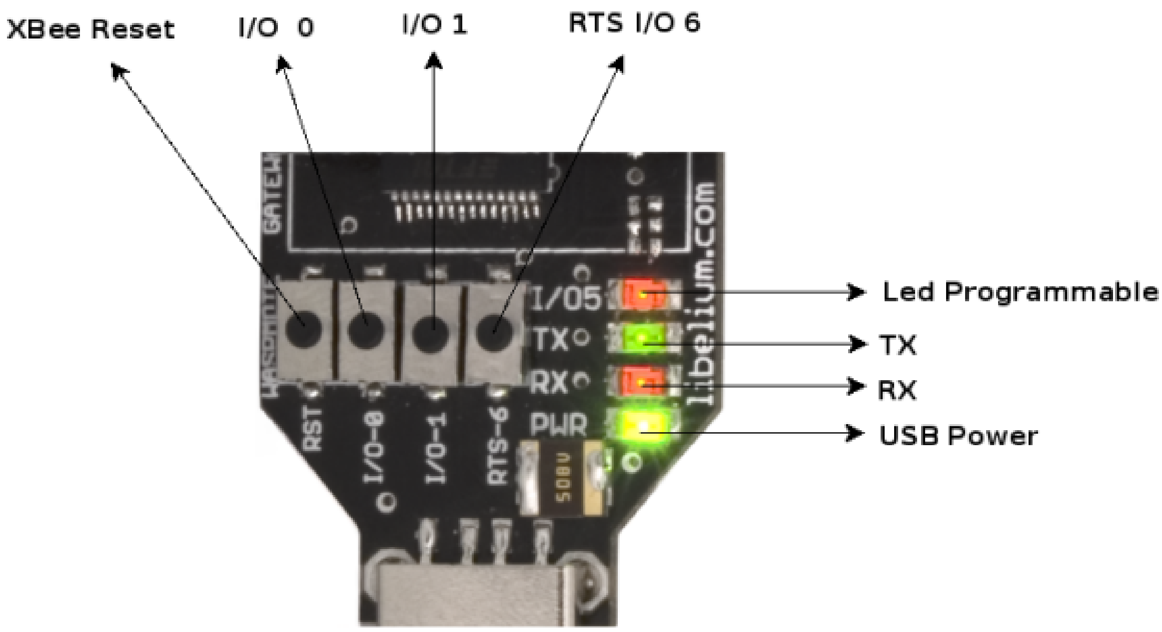

Figure 2.14: LEDs and buttons in Waspmote Gateway

b, Buttons

- Reset: allows the XBee module to be reset.
- I/O - 0: button connected to the XBee's I/O pin 0.
- I/O -1: button connected to the XBee's I/O pin 1.
- RTS - I/O – 6: button connected to the XBee's I/O pin 6.

All the buttons connect each one of its corresponding data lines with GND with when pressed. None of these have pull-up resistance so it may be necessary to activate any of the XBee's internal pull-up resistances depending on the required use.

Coordinator (Gateway) using to receive data from other nodes in the network. At this point, received data will be processing and syncing with computer, the Internet.

X-CTU is Digi's XBee configuration software. It makes communicating with XBees very easy, and provides a nice interface to modify all of the module's settings. When using it with the XBee WiFi's, it even provides a WiFi network scanning and connection interface to make connecting to networks a breeze.

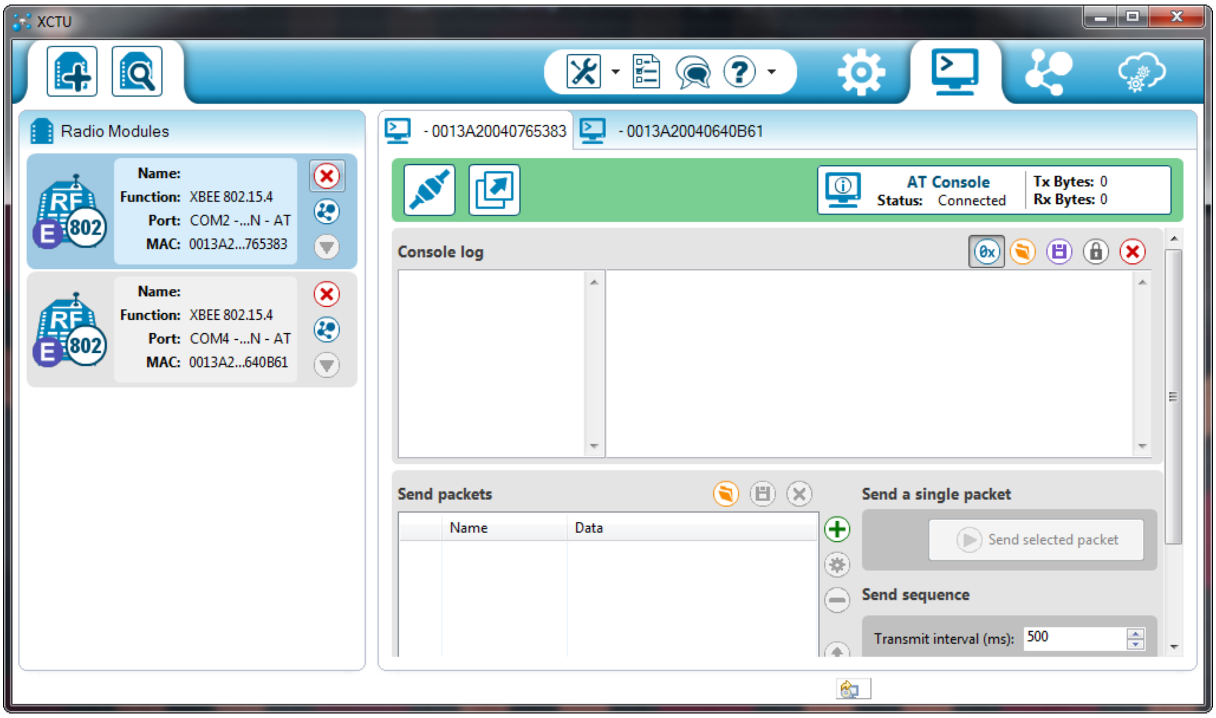

Figure 2.15: XBee Configuration & Test Utility (XCTU)

XCTU includes all of the tools a developer needs to quickly get up and running with XBee. Unique features like graphical network view, which graphically represents the XBee network along with the signal strength of each connection, and the XBee API frame builder, which intuitively helps to build and interpret API frames for XBees being used in API mode, combine to make development on the XBee platform easier than ever.

In order to do these things, a software needed call X-CTU with some following features:

- Manage and configure multiple RF devices, even remotely (over-the-air) connected devices
- The firmware update process seamlessly restores your module settings, automatically handling mode and baud rate changes
- Two specific API and AT consoles, have been designed from scratch to communicate with your radio devices
- Save your console sessions and load them in a different PC running X-CTU
- XCTU includes a set of embedded tools that can be executed without having any RF module connected:
  - **Frames generator**: Easily generate any kind of API frame to save its value.
  - **Frames interpreter**: Decode an API frame and see its specific frame values.
  - **Recovery**: Recover radio modules which have damaged firmware or are in programming mode.
  - **Load console session**: Load a console session saved in any PC running XCTU.
  - **Range test**: Perform a range test between 2 radio modules of the same network.
  - **Firmware explorer**: Navigate through XCTU's firmware library.
- An update process allows you to automatically update the application itself and the radio firmware library without needing to download any extra files

b, End Device

A node(End device) of network which consist of micro-controller, sensors and X-bee module to send data from sensor to gateway via Zigbee network using X-bee module.

These nodes would be design following pictures below similarly:

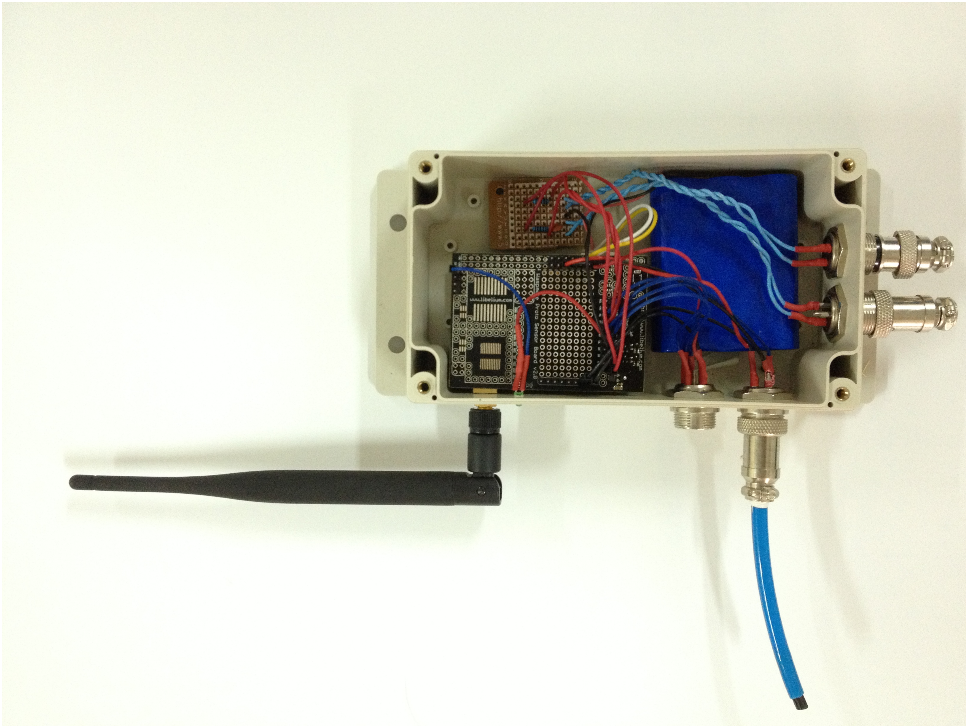

Figure 2.16: End Device

A system cannot working without software inside, so the Waspmote IDE need to upload code for micro-controller.

To use the Waspmote IDE compiler we must run the executable script called 'Waspmote', which is in the folder where the compiler has been installed.

Waspmote is divided into 4 main parts which can be seen in the following figure.

- The first part is the menu which allows configuration of general parameters such as the selected serial port.
- The second part is a button menu which allows verification, opening, saving or loading the selected code on the board.
- The third part contains the main code which will be loaded in Waspmote.
- The fourth part shows us the possible compilation and load errors, as well as the success messages if the process is carried out satisfactorily.

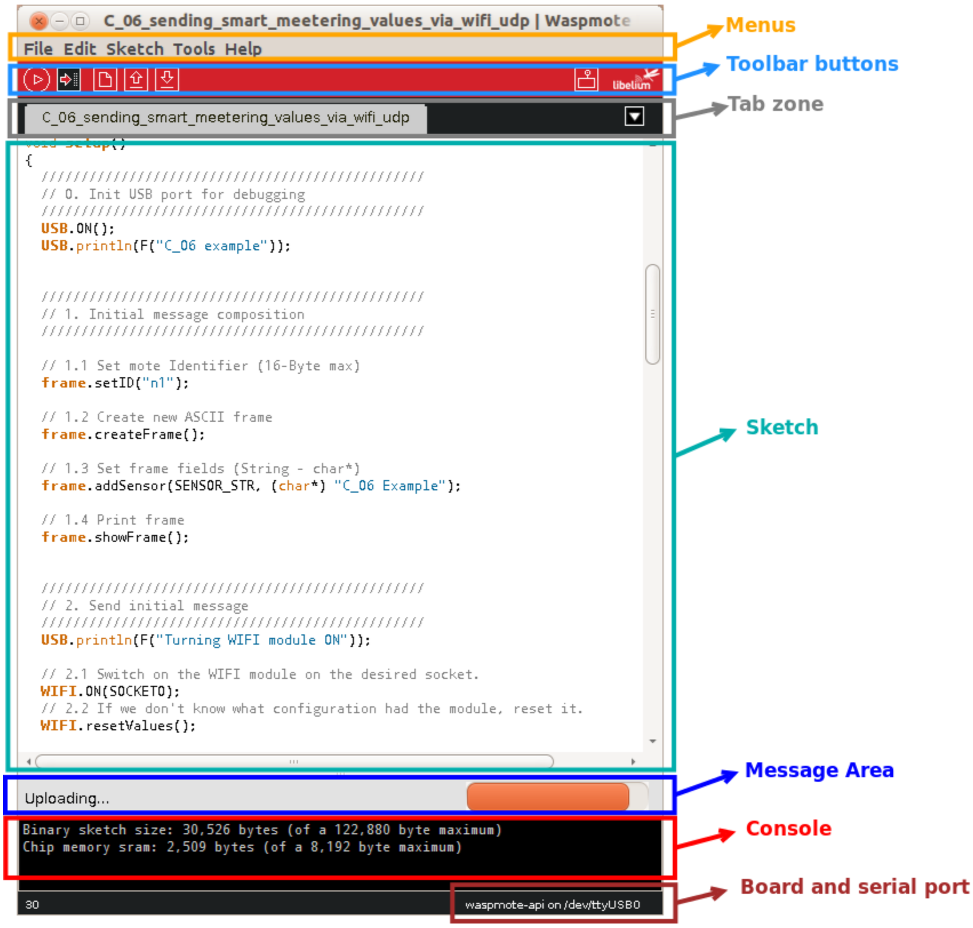

Figure 2.17: Waspmote IDE on Windows

Note: *The Gateway is just a UART-USB bridge. This means that the Gateway cannot be programmed and no code can not be uploaded. Its function is to pass data from the XBee to the USB, and vice-versa.*

2.3 ZigBee and IEEE 802.15.4

ZigBee technology is a low data rate, low power consumption, low cost, wireless networking protocol targeted towards automation and remote control applications. IEEE 802.15.4 committee started working on a low data rate standard a short while later. Then the ZigBee Alliance and the IEEE decided to join forces and ZigBee is the commercial name for this technology[5].

ZigBee is expected to provide low cost and low power connectivity for equipment that needs battery life as long as several months to several years but does not require data transfer rates as high as those enabled by Bluetooth. In addition, ZigBee can be implemented in mesh networks larger than is possible with Bluetooth. ZigBee compliant wireless devices are expected to transmit 10-75 meters, depending on the RF environment and the power output consumption required for a given application, and will operate in the unlicensed RF worldwide(2.4GHz global, 915MHz Americas or 868 MHz Europe). The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz.

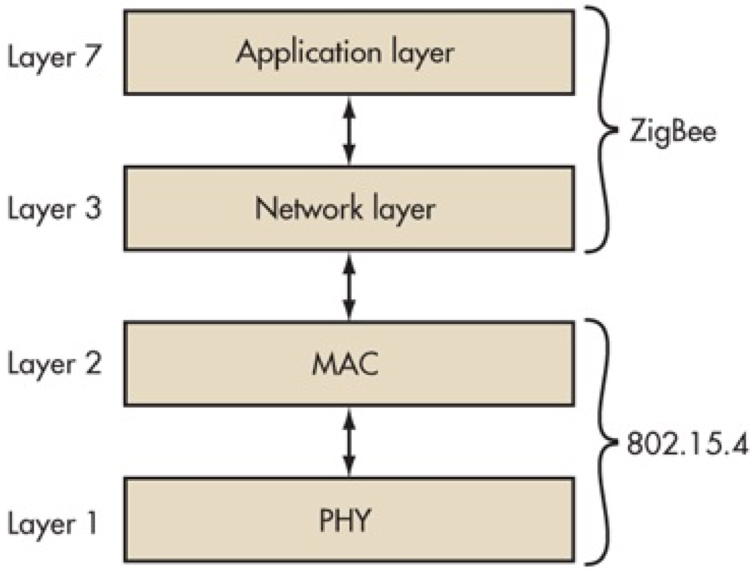

Figure 2.18: ZigBee and IEEE 802.15.4

IEEE and ZigBee Alliance have been working closely to specify the entire protocol stack. IEEE 802.15.4 focuses on the specification of the lower two layers of the protocol(physical and data link layer). On the other hand, ZigBee Alliance aims to provide the upper layers of the protocol stack (from network to the application layer) for interoperable data networking, security services and a range of wireless home and building control solutions, provide interoperability compliance testing, marketing of the standard, advanced engineering for the evolution of the standard. This will assure consumers to buy products from different manufacturers with confidence that the products will work together.

ZigBee is designed for devices talking to devices. It's great for the Internet of Things.

- Devices talking to other devices require less bandwidth and need to operate for years on a single battery.
- ZigBee mesh provides an easy to install reliable, self-configuring, self-healing network.
- ZigBee provides application level standards so a device functionality is defined and provides interoperability. For instance, LED light bulbs are defined and anyone with a ZigBee Certified product can interoperate with them.
- ZigBee was designed after Wi-Fi and Bluetooth and was designed specifically to co-exist with technologies in the ISM band.
- ZigBee networks choose the quietest channel in which to operate and can even change channels as conditions warrant.
- ZigBee devices are usually asleep and packets are small. These small packets usually have no troubles over-the-air.
- ZigBee is an acknowledgement based protocol and will re-send message if no acknowledgement is received.
- Because of streaming video and other high bandwidth uses, Wi-Fi is much more likely to interfere with Wi-Fi than it is with ZigBee.

Chapter 3

PROPOSED METHOD

3.1 Calibration

3.1.1 Why do we need to calibrate sensors?

There are a lot of good sensors these days and many are 'good enough' out of the box for many non-critical applications. But in order to achieve the best possible accuracy, a sensor should be calibrated in the system where it will be used. This is because:

- **Sensors cannot be perfect, it always have one or more errors.**
  - Sample to sample manufacturing variations mean that even two sensors from the same manufacturer production run may yield slightly different readings.
  - Differences in sensor design mean two different sensors may respond differently in similar conditions. This is especially true of 'indirect' sensors that calculate a measurement based on one or more actual measurements of some different, but related parameter.
  - Sensors subject to heat, cold, shock, humidity etc. during storage, shipment and/or assembly may show a change in response.
  - Some sensor technologies 'age' and their response will naturally change over time - requiring periodic re-calibration.

- **The Sensor is only one component in the measurement system.**
  For example:
  - With analog sensors, your ADC is part of the measurement system and subject to variability as well.
  - Temperature measurements are subject to thermal gradients between the sensor and the measurement point.
  - Light and color sensors can be affected by spectral distribution, ambient light, specular reflections and other optical phenomena.
  - Inertial sensors are sensitive to alignment with the system being measured.

3.1.2 How to calibrate sensors?

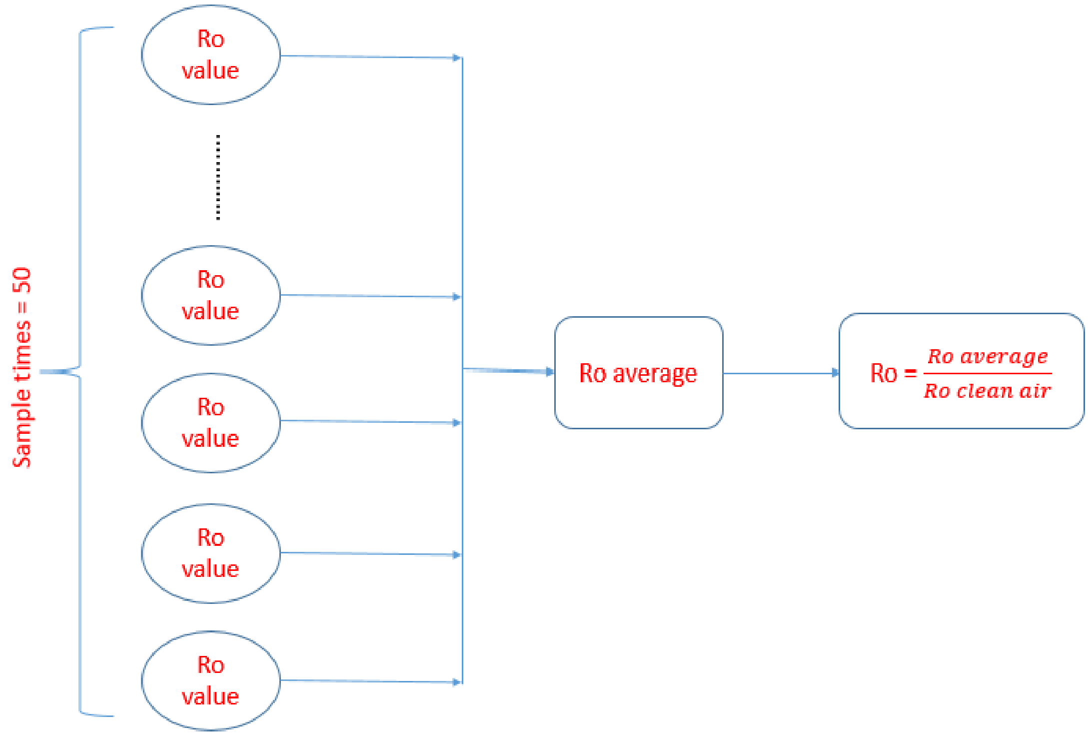

Figure 3.1: Flow chart to calibrate MQ-2 sensor.

This function assumes that the sensor is in clean air. Then, it's calculate the sensor resistance in clean air and divide it with Ro (sensor resistance in clean air Ro = 9.83, which differs slightly between different sensors).

3.2 Data frame

3.2.1 ASCII Frame

These frames are supposed to facilitate the comprehension of the data to be sent. As the frame is composed by ASCII characters is easier to understand all the fields included within the payload.

It is possible to identify two different parts inside the frame. The first one corresponds to the header and its structure is always the same. The second one corresponds to the payload and it is where the sensor values are included.

The following figure describes the ASCII Frame structure:

Table 3.1: ASCII Frame

HEADER										**PAYLOAD**						
<=>	Frame Type	Num Fields	#	Serial ID	#	Waspmote ID	#	Sequence	#	Sensor 1	#	Sensor 2	#	...	Sensor n	#

a, ASCII Header

The structure fields are described below with an example:

Table 3.2: ASCII Header

HEADER										**PAYLOAD**					
<=>	0x80	0x03	#	35690284	#	NODE1	#	214	#	Temp:35	#	GPS:31.200;42.100	#	Date:16-01-01	#
A	B	C	D	E	D	F	D	G	D	Sensor1	D	Sensor2	D	Sensor3	D

A → Start Delimiter [3 Bytes]: It is composed by three characters: "¡=¿". This is a 3-Byte field and it is necessary to identify each frame starting.

B → Frame Type Byte [1 Byte]: This field is used to determine the frame type. There are two kind of frames: Binary and ASCII. But it also defines the aim of the frame such event frames or alarm frames. This field will be explained in the following sections.

C → Number of Fields Byte [1 Byte]: This field specifies the number of sensor fields sent in the frame. This helps to calculate the frame length.

D → Separator [1 Byte]: The '#' character defines a separator and it is put before and after each field of the frame.

E → Serial ID [10 Bytes]: This is at most a 10-Byte field which identifies each Waspmote device uniquely. The serial ID is get from a specific chip integrated in Waspmote that gives a different identifier to each Waspmote device. So, it is only readable and it can not be modified.

F → Waspmote ID [0Byte-16Bytes]: This is a string defined by the user which may identify each Waspmote inside the user's network. The field size is variable [from 0 to 16Bytes]. When the user do not want to give any identifier, the field remains empty between frame's separators: "##".

G → Frame sequence [1Byte-3Bytes]: This field indicates the number of sequence frame. This counter is 8-bit, so it goes from 0 to 255. However, as it is an ASCII frame, the number is converted to a string so as to be understood. This is the reason the length of this field varies between one and three bytes. Each time the counter reaches the maximum 255, it is reset to 0. This sequence number is used in order to detect loss of frames.

b, ASCII Payload

The frame payload is composed by several sensor data. All data sent in these fields correspond to a predefined sensor data type in the sensor table. This sensor table is stored in Meshlium (gateway of the network) and it will be used in order to interact with the database.

There are three types of ASCII sensor fields:

- **Simple Data:** Sensor field is composed by a unique data. The format is: "sensor_label:value" and a separator character [#] is set at the end of the value.
- **Complex Data:** This is the format used to send data composed by two or three

values. The format is: “sensor_label:value; value; value“ and a separator character [#] is set at the end of the last value.

- **Special Data:** Date and time are defined in a special format.

3.2.2 Binary Frame

This frame type has been designed to create more compressed frames. The main goal of defining binary fields is to save bytes in frame’s payload in order to send as much information as possible. The main disadvantage is the legibility of the frame.

As the ASCII frames, the Binary frames are also composed by two different parts: header and payload. The header of the Binary frame is quite similar to the ASCII frame except for the frame sequence number and the separator at the end of the header.

The following figure describes the Binary Frame structure:

Table 3.3: Binary Frame

HEADER							**PAYLOAD**			
<=>	Frame Type	Num Fields	Serial ID	Waspmote ID	#	Sequence	Sensor 1	Sensor 2	...	Sensor n

Chapter 4

RESULTS AND DISCUSSIONS

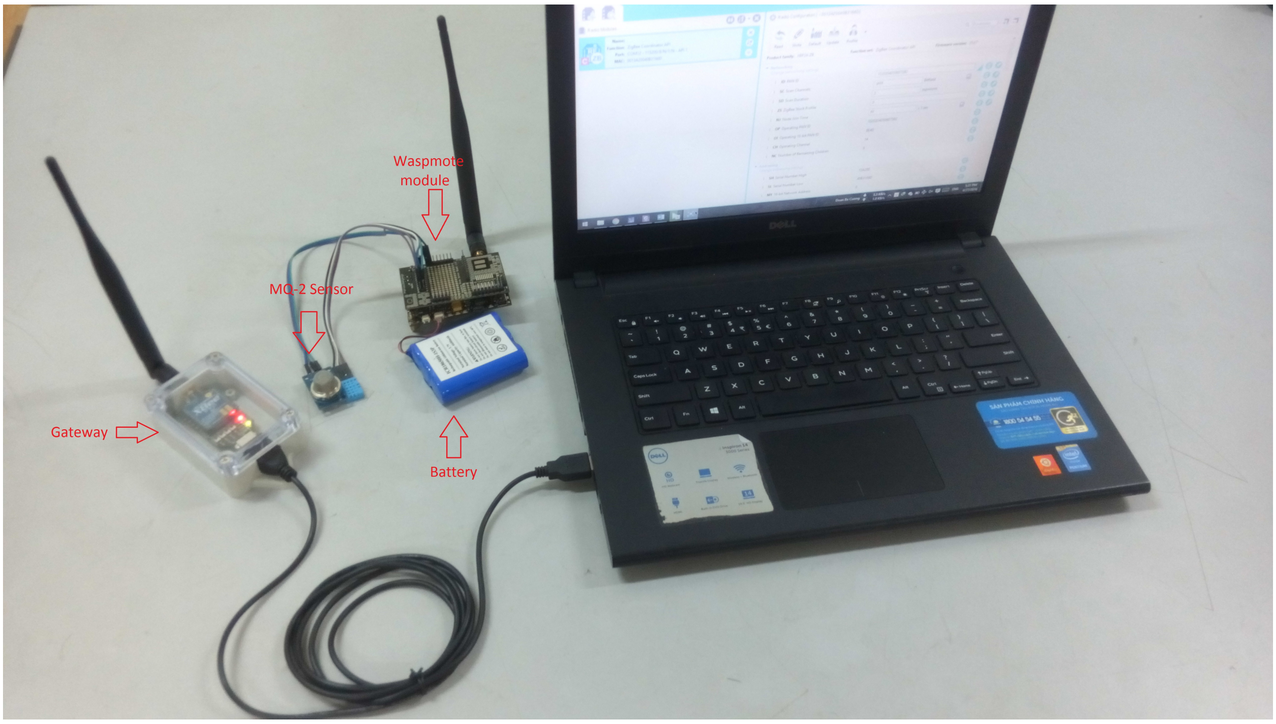

Figure 4.1: System modeling.

At this thesis, a system use frame following table below:

Table 4.1: ASCII Frame of the system

HEADER										**PAYLOAD**					
<=>	#	ID Node	#	Node Number	#	Packet Number	#	Battery	#	LPG	#	CO	#	SMOKE	#

For example:

<=>#382553448#Node_1#1#BAT:28#LPG:3.609#CO:2.238#AP1:13.419#

We can receive these information:

- ID Node: 382553448
- Number Node: Node_1
- Packet Number: 1
- Battery Level: 28
- LPG Level: 3.609 ppm
- CO Level: 2.238 ppm
- Smoke Level: 13.419 ppm

4.1 Data transfer rate

An experiment, a system can transfer data with different distances so we can determine the data transfer rate and choose the best distance for system setting up.

Table 4.2: Data transfer rate in case 1 node and 5m distance.

Sent Number	**Send Packet**	**Receive Packet**	**Data transfer rate**
1	100	100	100%
2	200	197	98.5%
3	300	300	100%
4	400	398	99.5%
5	500	499	99.8%

The result show that when the distance between a node and a gateway is 5 meter, gateway can be received almost package were send from end device. It's about over 99% of packages.

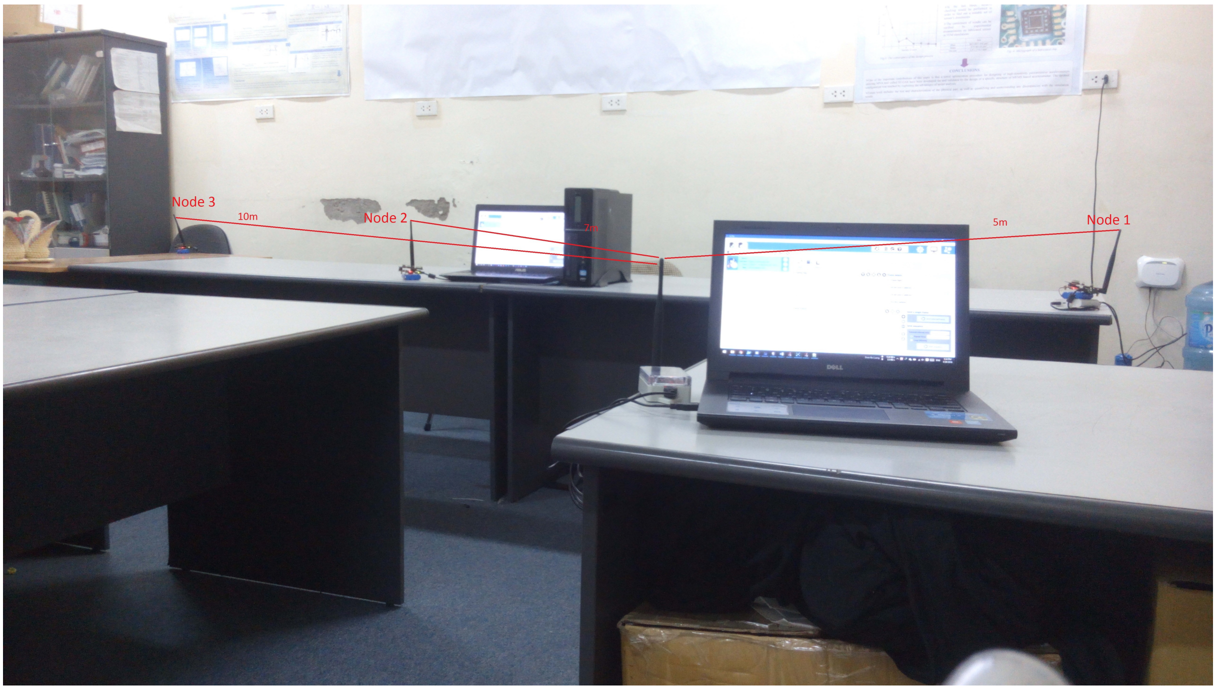

Figure 4.2: System modeling in case 3 node and 5m,7m,10m distance respectively.

Table 4.3: Data transfer rate in case 3 node and 5m,7m,10m distance respectively.

Node Number	**Send Packet**	**Receive Packet**	**Data transfer rate**
1	180	157	87.22%
2	180	157	87.22%
3	180	155	86.11%

In the second condition, 3 nodes put on three different positions in a room and with the different distances to gateway from 5m, 7m, 10m for node 1, node 2, node 3 respectively. The environment with no objects. The picture above describe position of nodes and gateway in one room. Finally, only about 87% packages received at gateway successfully.

Figure 4.3: System modeling in case 3 node and 10m,20m,50m distance respectively.

Table 4.4: Data transfer rate in case 3 node and 10m,20m,50 distance respectively.

Node Number	**Send Packet**	**Receive Packet**	**Data transfer rate**
1	180	165	91.67%
2	180	165	91.67%
3	180	166	92.22%

The third condition, 3 nodes put on three different positions in a building and the distances from these nodes to gateway from 10m, 20m, 50m for node 1, node 2, node 3 respectively. The environment have some object like wall, people go around, human voices and some furniture in a building. A system is described by the following picture above. The result show in the table above pointed out that the average package received at gateway is about 92%, it's good for a wireless sensor network in wide area.

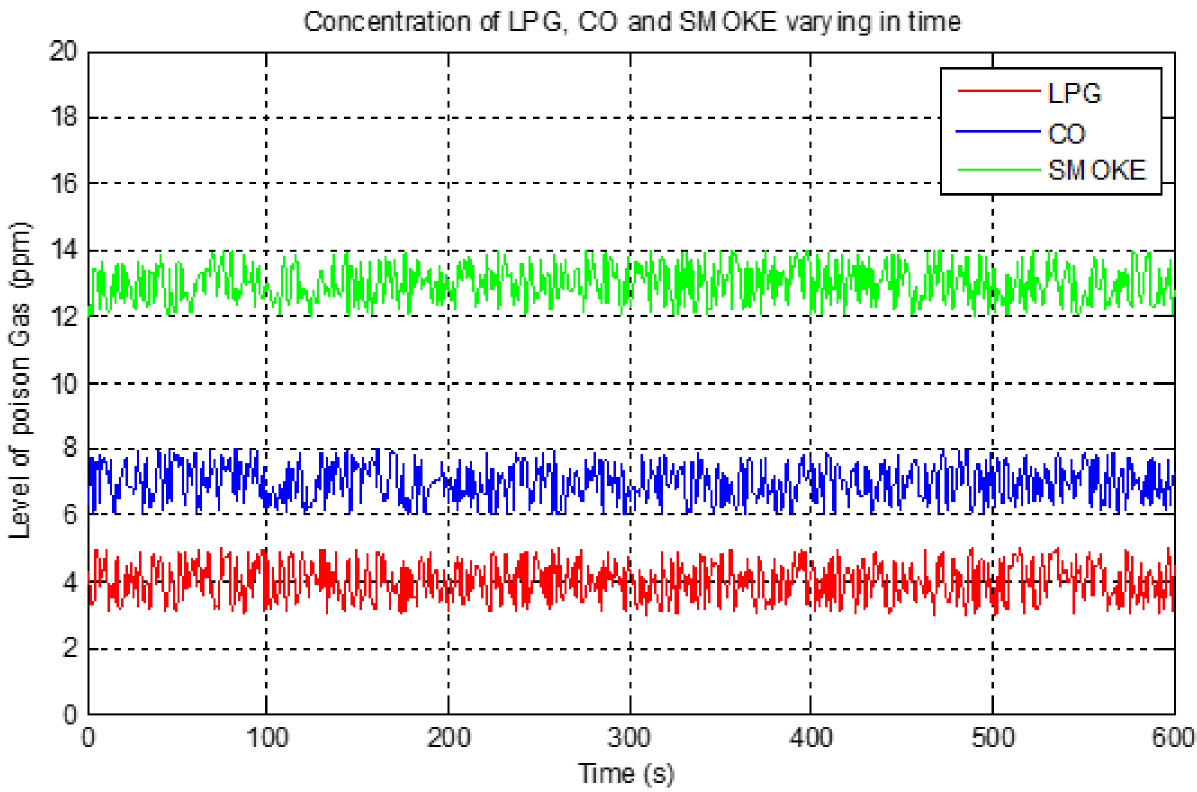

Figure 4.4: Concentration of LPG, CO and SMOKE for a period of time

4.2 A system's life time

Although, the system set up in buildings with the power supply by building, sometimes the power supply for buildings not working very well so this system should be have an own power supply.

Power supply: 6600 mAh Vout = 3.7 V

Apply Electrical power equation: Power P = V x I (mWh).

The electrical power of battery: P = 6600 x 3.7 = 24420 (mWh).

A node consists of Waspmote module, XBee module and MQ-2 sensor. Total energy of the system equal to the energy of all components in system.

- Waspmote module:
  - Current: 15 mA
  - Voltage: 3.3 v

$$P = 15 \text{ x } 3.3 = 49.5 \text{ (mW)}$$

- XBee module
  - Current: 15.2 mA
  - Voltage: 3.3 v

$$P = 15 \text{ x } 3.3 = 50.16 \text{ (mW)}$$

- MQ-2 Sensor
  - It's about 800 mW (From MQ-2 datasheet).

A node will read and transfer data continuously without any rest at time, so the total electrical power of the system:

$$\mathbf{P = 49.5 + 50.16 + 800 = 899.66 \ (mW)}$$

A system's life time when the remaining electrical power bigger than zero and be calculated by the following equation:

$$\textbf{A system's life time} = \mathbf{24420/899.66 = 27.14 \ (h)}$$

The life time of the system only need when the power supply of buildings is shut down or have a trouble. After one more day, the system still working and this amount of time enough for supply power again.

An experiment is represented by the following link:

`https://www.youtube.com/watch?v=8lf3CGbckS0`

Chapter 5

CONCLUSIONS

5.1 Conclusions

The objective of this thesis: Indoor air quality monitoring for smart building. I focused on research and design a wireless sensor network to monitor poison gas in smart building or some places in the citizen. Through the process of learning, research, analysis and design, this system has some highlights:

- Thesis research and design a system to monitor the concentration of air pollution using gas sensor and wireless sensor network.
- Calibrating the device to make the data more reliable before reading and analyzing data received from the sensor. And then, sending data to the gateway after package them.
- With this simple system, it would be feasible to determine the level of poison gas in the air of buildings, so that it can be warning people living or in here to protect them. It has a good application value.

5.2 Future Works

We consider to develop a network with a hundred of nodes to build a system monitoring poison gas (LPG, CO, CO2, ...), temperature, humidity. At that time, the system must have some algorithm to send find the best way from node to gateway via other neighbor nodes. Moreover, it can integrate or replace to camera system in buildings and the data will be sent to the web (Internet of things), send message to the monitors.

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