CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

MASTER THESIS

Cooperation of Home Automatization Systems with Sensors in IoT network

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ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Fakulta/ústav: **Fakulta elektrotechnická**
Zadávající katedra/ústav: **Katedra telekomunikační techniky**
Studijní program: **Komunikace, multimédia a elektronika**
Studijní obor: **Komunikační systémy**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Spolupráce domácích automatizačních systémů se senzory v sítích IoT

Název diplomové práce anglicky:

Cooperation of Home Automatization Systems with Sensors in IoT Networks

Pokyny pro vypracování:

Navrhněte a realizujte systém umožňující získávání dat z inteligentních elektroměrů a jejich odesílání do systému domácí automatizace skrze IoT síť Sigfox. Systém navrhněte tak aby bylo využito všech možností technonologie Sigfox a přitom se neporušovala pravidla pro využívání ISM sítí. Pro operační systém Linux navrhněte a realizujte datový konektor, který umožní přenést data ze sítě Sigfox do systému domácí automatizace pomocí některého z protkolů domácí automatizace (KNX, M-Bus apod.)

Seznam doporučené literatury:

[1] Materials available on https://openwrt.org [on-line]
[2] Materials available on https://www.sigfox.com/en [on-line]

Jméno a pracoviště vedoucí(ho) diplomové práce:

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Datum zadání diplomové práce: **14.03.2018** Termín odevzdání diplomové práce: __________

Platnost zadání diplomové práce: **30.09.2019**

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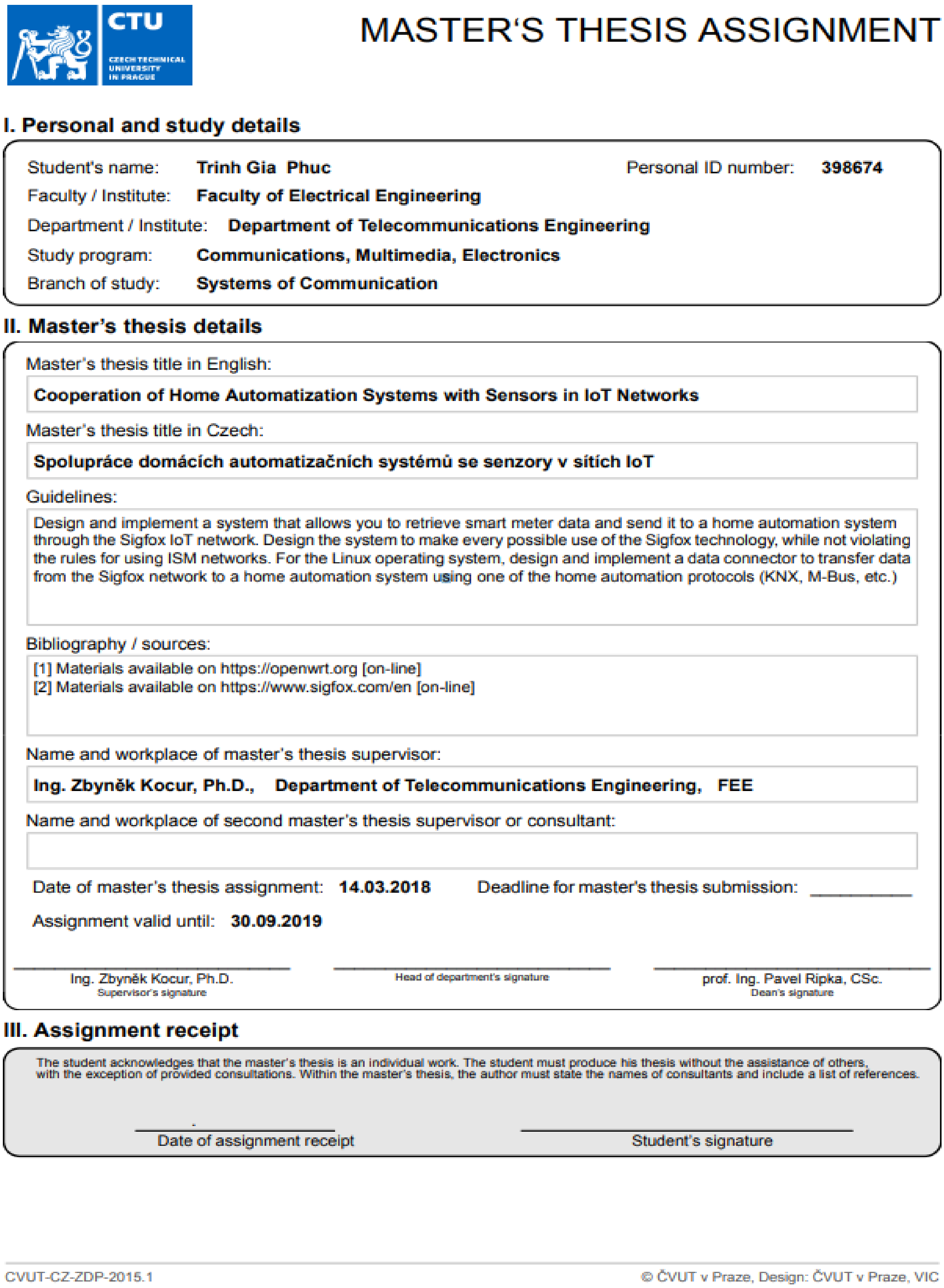
III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

Datum převzetí zadání

Podpis studenta



MASTER'S THESIS ASSIGNMENT

I. Personal and study details

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Department / Institute: **Department of Telecommunications Engineering**

Study program: **Communications, Multimedia, Electronics**

Branch of study: **Systems of Communication**

II. Master's thesis details

Master's thesis title in English:

Cooperation of Home Automatization Systems with Sensors in IoT Networks

Master's thesis title in Czech:

Spolupráce domácích automatizačních systémů se senzory v sítích IoT

Guidelines:

Design and implement a system that allows you to retrieve smart meter data and send it to a home automation system through the Sigfox IoT network. Design the system to make every possible use of the Sigfox technology, while not violating the rules for using ISM networks. For the Linux operating system, design and implement a data connector to transfer data from the Sigfox network to a home automation system using one of the home automation protocols (KNX, M-Bus, etc.)

Bibliography / sources:

[1] Materials available on https://openwrt.org [on-line]
[2] Materials available on https://www.sigfox.com/en [on-line]

Name and workplace of master's thesis supervisor:

Ing. Zbyněk Kocur, Ph.D., Department of Telecommunications Engineering, FEE

Name and workplace of second master's thesis supervisor or consultant:

Date of master's thesis assignment: **14.03.2018** Deadline for master's thesis submission: __________

Assignment valid until: **30.09.2019**

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prof. Ing. Pavel Ripka, CSc.
Dean's signature

III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

Date of assignment receipt

Student's signature

Abstract

Nowadays, the Internet of Things (IoT) is developing rapidly and vastly expanding in scale. Along with its development are the technologies behind which create the eco-system based on the Internet backbone to collect and process the data from sensors (or ‘things’) to end user which need to be implemented according to their applications.

As the IoT is a target to many fields of application and its tension is to update the existing infrastructures in order the upgraded system can be connected to the backbone internet with minimal efforts included cost and installation.

The goal of the thesis is to design and implement a system that retrieves the data from the smart power meter and send collected data through IoT network using common current technology such as LoRa to a custom back-end server. On the other hand, the custom back-end server will be implemented in such a way that it can prepare the collected data and prepare reception data for home automation systems, in which running on a standardized protocol for home automation such as KNX.

KEYWORDS: LoRa, LoRaWAN, Home automation network, sensor in IoT network, KNX, Power meter.

Acknowledgment

I wish to express my sincere thanks to my supervisor Ing. Zbyněk Kocur, Ph.D., for providing me with all the necessary facilities for the research as well as for his sharing expertise, experiences and valuable advice.

I take this opportunity to express gratitude to all teachers of the Electrical engineering faculty for their teaching and support.

I also thank my family for the encouragement, support, and attention which they intended for me through this venture.

Declaration

“I hereby declare:

- that I have written this writing thesis without any help from others and without the use of documents and aids other than those stated in the Bibliography.

- that I have mentioned all the sources used and that I have cited them correctly according to established academic citation rules.”

Phuc Trinh Gia

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Prague, 2019

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Chapter 1

Introduction

1.1 Purpose and structure of the thesis

The purpose of the thesis is to analyze the current situations of power monitoring in households in the Czech Republic with power meter as well as the using of the home automation system to regulate the power consumption for users/customers or utilities. Base on the analysis, advantages, and disadvantages of the current systems will be considered and evaluated for figuring out current problems, thus, the proposed solution will follow on for solving the problems. The aim of the proposed solution is to focus on the application of IoT technologies for transferring the data from power meter to end customer, specified in this thesis as a home automation network (HAN). The proposed solution deals with the breaking data into several data streams with several data protocols used across the data transfer procedure. The solution is not only dealing with how to transfer the data from the power meter to the Internet but also resolving the data from the Internet to the HAN. During the implementation of the design, there are some studies about a couple of fields and technologies are included such as LoRaWAN network, KNX home automation standards, and KNX IP protocol.

Chapter 1 – Introduction. This chapter is an introduction of materials and tools used for building the project on a hardware point of view as well as software.

Chapter 2 – Analysis of network and technologies. This chapter focuses on studying of current network and technologies using on the internet of thing and home automation network. In the chapter, the detail study cases for current usages of power smart meter with current IoT and HAN network are discussed in detail. This analysis helps to figure out the problems existing in the current infrastructures and create a basement for the next chapter in the design proposition.

Chapter 3 – Motivation and proposed design. Regarding the problems found in chapter 2, this chapter continues the study and analysis about integrating power meting into home automation network with real-life demands. The study included the motivation to solve the current problem of monitoring power consumption for some critical properties in the Czech Republic and following by the proposed solution. The proposed solution comes together with the suggested design for solving the problem in which the LoRa technology is invoked to deal with current obstacles.

Chapter 4 – LoRaWan technology and application. Inherited from chapter 3, in this chapter, the study of LoRaWAN technology is considered in order to cover all crucial features which are for the implementation of LoRaWAN with the power meter. On the other hand, the first part of the implementation for the proposed design in chapter 3 is explained in detail.

Chapter 5 – KNX and application. In this chapter, the study and discussion about KNX will be carried out in order to classify one of the most common technology used in home automation and advanced metering infrastructures (AMI). Following the study is the detail explanation of the second part of implementation for the proposed design.

Chapter 6 – Conclusion. The final discussion about the project for the proposed solution and design.

1.2 Hardware and software overview

In order to retrieve data from the power meter, the extra system on chip-based board (exchange board) is used for this purpose and connect with the meter via standard optical port (IEC 62056) by the optical-serial converter. On the other side, the board connects with LoRa module through the UART interface. The list of elements and their descriptions are listed below.

List of elements used to construct the hardware part:

- Digital power meter Landis-Gyr E350 used for measuring power consumption and other electrical quantities such as electric-current, voltage, frequency, power factors, etc. This meter is equipped with the optical port for purpose of external communication with other devices. In this project the optic – USB adapter is used for serial communication with the exchange board.
- Olinuxino – RT5350F is an embedded computer used as an exchange system for collecting data from the power meter and sending data to LoRa module for on-air transmission.
- LoRa module with RN2483 chip is used for sending data over the air to LoRaWAN network.

➢ Digital power meter Landis-Gyr E350 provides the measurement of power consumption and other electrical quantities in household grids and it support data read-out of data through many communication ports such as Ethernet, RS485 and Optical port.

Figure 1. The sample power meter for data reading

➢ Olinuxino – RT5350F is system on chip-based board which is used in this project as an exchange board for retrieving data from the power meter and then send them to LoRa module for over air transmission. The board using RT5350F system on chip (SoC) which has enough power to run a small embedded Linux operating system on it and performing scheduled communication for power meter read-out and LoRa transmission. The board supports two serial ports (UART) for communication with a power meter and LoRa module.

Figure 2. Olinuxino RT5350F EVB as exchange board

➢ LoRa module RN2483 provides dual-band 433/868Mhz based on LoRa Technology, the module is acquired with UART serial communication for interfacing with exchange board.

Figure 3. LoRa RN2483 end device

- Software tools for the projects are used by the following components:OpenWrt: Linux operating system for embedded devices and it is installed on RT5350F.
- Lua Scripting: This scripting language is used for creating the scripts which are running on RT5350F exchange board. These scripts response for reading the data from power meter and forward them to LoRa module for on air transmission.
- Python: This scripting language is used for creating the scripts which are running on virtual host machine with CentOS 7.0 server operating system. These scripts represent the implementation of network server, KNX server and Client

Chapter 2

Analysis of Networks and Technologies

2.1 Overview of a smart power meter

The smart power meter is the next generation of an analog power meter, its functions is inherited from analog one that measures the consumption of electrical power (some other case even with water and gas consumptions). It is called ‘’smart’’ because it is not only simply measuring the power consumption but also can collect data in intervals of an hour and transfers that information at least daily back to the utility for monitoring and billing. Smart power meter enables two-way communications between the central system and itself. Unlike home energy monitor, smart meters can gather data for remote reporting. Communication between smart power meter to the network can be done via fixed connections or via wireless. Before going more into the technical specification of power meters, there are some several important benefits that smart power meter brings to users (customers) and power companies.

In this section, the general architecture of a smart power meter is considered. It is not only concern about hardware specifications but also an emphasis on the aspect of communication protocols. The figure below demonstrates the typical hardware of a smart power meter.

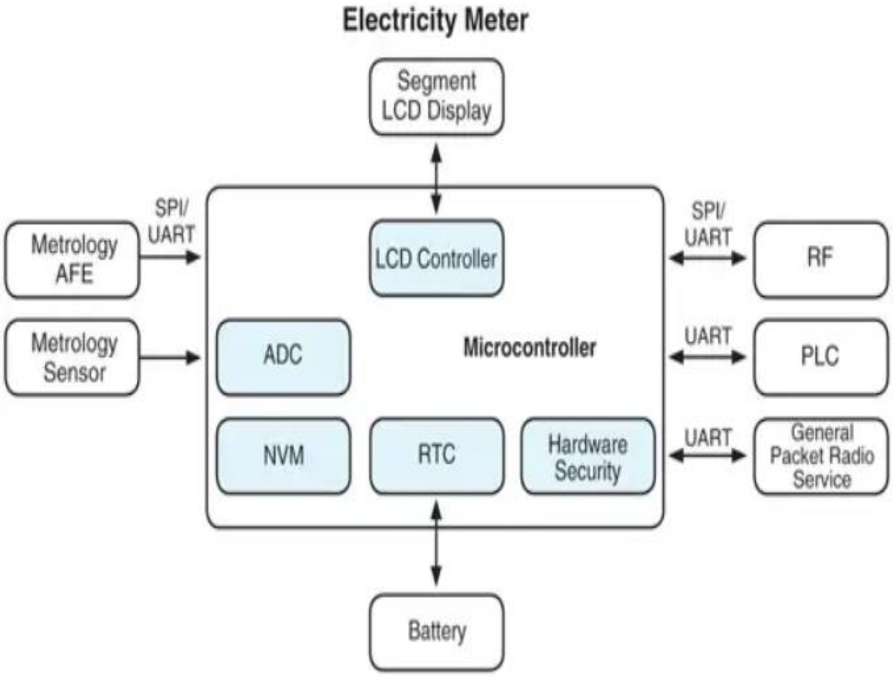


Figure 4. Hardware demonstration of smart power meter

On hardware point of view for communications, smart meters are designed to have local communication for HAN and long ranged communication for Internet or IoT network. For local communication with HAN systems or terminals, typical standards are used such as USB/WIFI, Serial communications (USART, UART), two-wire communications. On the other hand, for long-range communication, radio frequency is implemented using such technology like LoRa, WiMAX, Sigfox, etc or mobile network like EDGE, LTE.

On the aspect of communication protocols, there are many protocols are used for different purposes. For example, if the power meter is required to connect to the HANS system, it can use wire/wireless protocol such as Bluetooth, Zigbee, Z-wave, DSLM/COSEM, KNX, etc. On the other hand, if the power meter is needed to connect to neighbor devices (in long-range communication) or to utilities it can use DSLM/COSEM, internet gateways. Currently, in the Czech Republic, the most common installed version of the power meter is only IR header, then GPRS/EDGE. Other communication technologies such as Ethernet, RS485 KNX, DLSM/COSEM could be used in next years. In near future will be the IR interface unlock for common users using. They could use their own interconnection to this interface.

2.2 Home automation network

A home automation network is a network where electrical devices in a home are connected to a central system that automates those devices under user inputs. As the technologies have been changing, those electrical devices are added together with sensors and connected to the Internet. Thus, users can remotely monitor, scheduling, controlling those devices according to their needs. The futures of those devices are going into next states where they are becoming smart, which mean these devices can communicate with each other and make their own decision based on the usage of users or by the conditions of the environment around them. The typical of HAN network is shown in the figure below.

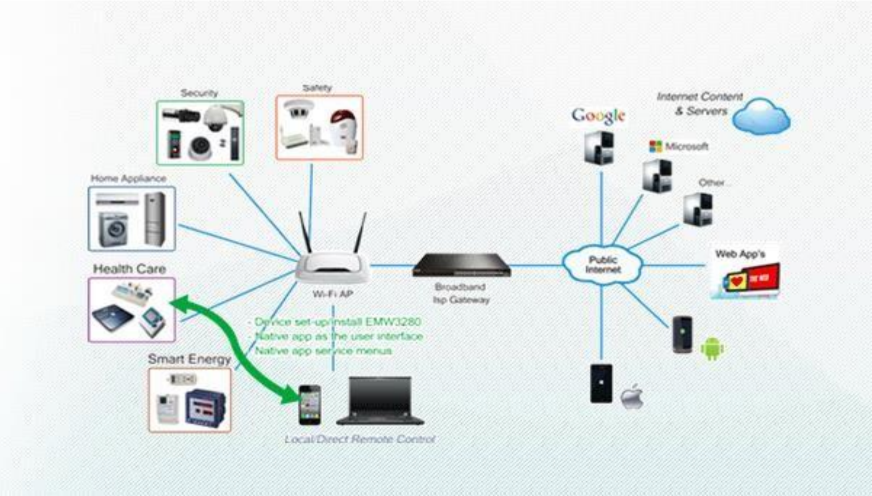


Figure 5. The topology of the HAN network

From figure 1, the typical communications of HAN to users are through Internet gateway such as routers or through mobile networks such as 3G, 4G networks and toward the backbone network of the Internet. The central processing unit of HAN network is designed to communicate with sensors and actuators inside a building or house through many communication protocols from wired to wireless methods such as Ethernet, Serial ports, Z-wave, Zigbee, Bluetooth, etc.

Base on its architecture, the HAN is constrained for a single home or a building thus causes several disadvantages on its functions:

- The data from the HAN network is streaming data and required the gateway must be connected to a high-speed internet connection. Besides that, the connection to the Internet is totally depended on the Internet backbone network.
- Extending the scale of the network is limited by communication protocols. For example, the internal devices (sensors, actuators) are connected with the central controller by wireless communication protocols (Zigbee, Z-wave, Bluetooth, Wifi,

etc) with the maximum distance is 10- 300 m (depended on protocols). Obviously, the network is extensible by adding nodes through networks, however, it creates more complexities and extra cost for installation as well as maintenance of the system.

- The main objects (house, buildings) in the network can communicate with each other (depends on applications) with the Internet connections (if the distance excesses the maximum distance of above) or when they are in the range of wireless protocols. Once again, if we need to extend the communications among objects, wire communication protocols (Ethernet, Serials) are considered. However, the distances again are problems because the distances for these protocols are also limited and the cost will be raised up.
- On the aspect of utilization convenience, each HAN system is manufactured by different manufacturer thus it causes synchronization for the system. For example, if users want to add extra internal devices (sensors or actuators) they need to select the devices with the same protocols or some time from the same manufacturer. Furthermore, the application services are also provided differently by each manufacturer.

2.3 Internet of Things

Internet of thing (IoT) is a network where all devices in the network are interconnected and communicate with each other for collecting and sharing data. The term IoT is very large which covers many applications. However, the main purpose of IoT is leading to smarter solutions and providing big data for all aspects of life. From the perspective of how IoT devices are interconnected and operate the Internet Architecture Board classified them into the following class:

- IoT Device-to-Device model: Two or more devices directly connected through a shared network.
- IoT Device to cloud model: in this model IoT sensors or devices connected straight through cloud services.
- IoT Device-to- gateway model: in this model sensors and other IoT devices are connected to a local application gateway, which is used to process the data gathered by IoT devices before sending them to the Cloud. In this model, the application gateway is always considered as an intermediate server between IoT devices and clouds.
- IoT Back-End-Sharing-Data model: this model enables IoT devices to transfer data to a cloud service for analysis along with data from gathered from other IoT devices or sources.

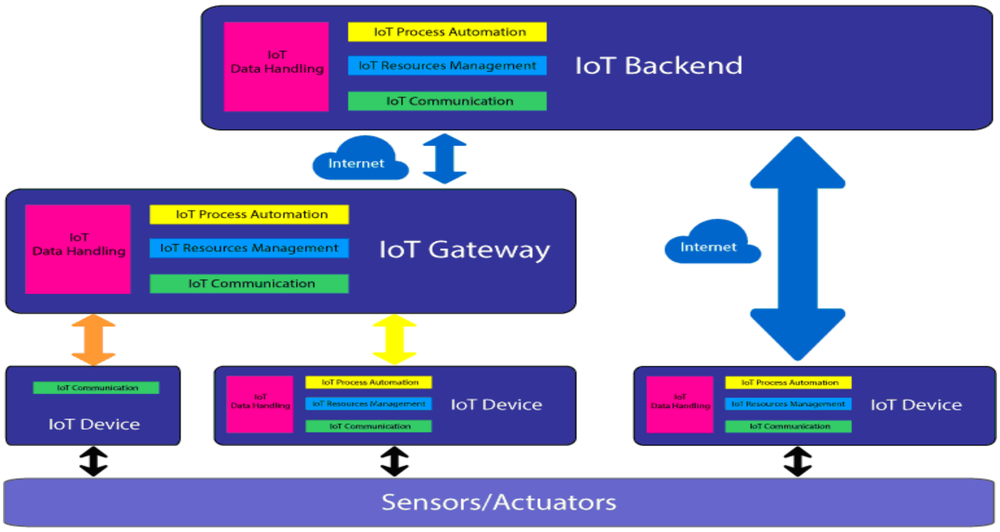


Figure 6. The topology of IoT network

One of the most important elements operates in IoT network is sensors, they are tiny embedded devices with limited power and computational ability and used for collecting data and monitoring the environment around them such as temperatures, humidity, pressure, heat, power, etc. Besides that, as the technology is growing up, they are intended for using wireless communications for reducing complexity and cost meanwhile increasing range efficiency. This idea generated a definition of Wireless Sensor Network (WSN) operating in the IoT network. **[1]**

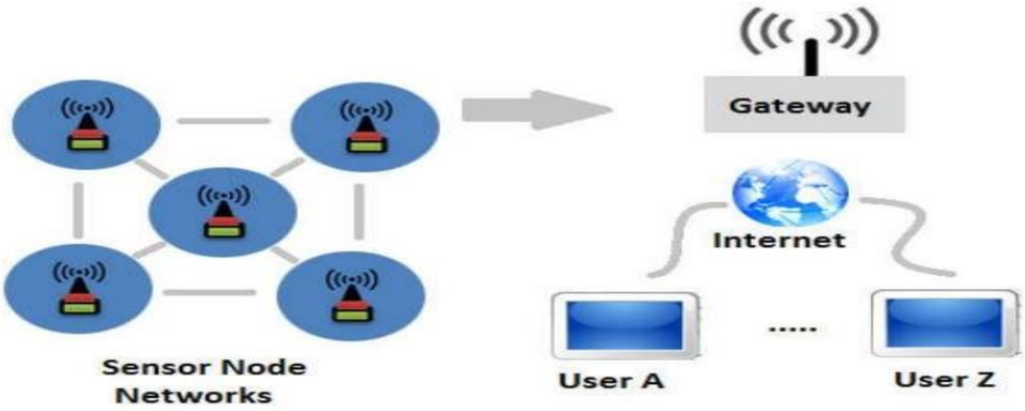


Figure 7. The topology of WSN in IoT network

This idea is the main characteristic using in this project because each power meter will be considered as an individual node. The detail will be explained in the next sections.

The wireless sensors networks using IoT network has specific characteristics described as below:

- The IoT network itself uses specific radio technologies providing ultra-low power consumption which mean that the sensors can run with battery sized power supplies and lasts for years.
- The radio technology which is designed for IoT network with long-range communication with the low data rate. In general, technologies such as LoRaWAN, Sigfox or NB-IoT provide the connection distance from sensors to gateways with a range from 2 - 10 Km depends on the topography of terrain where the system is installed. On the other hand, the transfer data rate for these

systems are also limited to 10 – 10000 bps and messages per day are around 140 - 250 messages per day (5 - 10 messages per hour).

2.4 Analysis of the usages of the power meter in Home Automation Network

In this section, the possibilities of connection of smart power meter to HAN and IoT are considered.

a. Case 1: Smart power meter is directly connected to the HAN controller

There are several types of integrating smart power meter to HAN system because HAN systems support multi-connection flat-form (Wire/wireless) thus smart power meter can become a part of sensors/actuators in HAN system by communicating with the central controller of HAN. The demonstration of this design can be shown in the figure below.

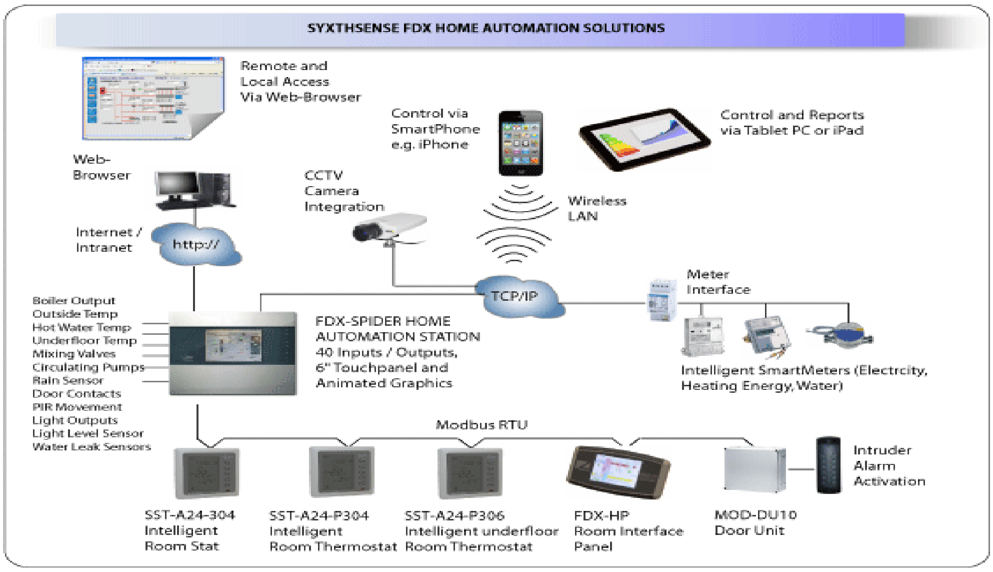


Figure 8. Smart power meter connected to the central controller

With this configuration, the data from the smart power meter is directly connected to the application server by Internet gateway. However, there are some several issues with this model:

- Data is mixed with stream data from other devices, require a special way of access to the application layer on the server as well as the central controller of HAN.
- This method also limits the ability to create a connection to the neighbor network area (NAN). There is no possibility for interfacing with IoT
- The power meter needs to be preprogrammed in order to communicate with the central controller. As mentioned before, each manufacturer has different protocols thus the compatibility of the smart power meter is limited.
- The smart power meter must be installed within the communication range of the HAN controller.

b. Case 2: Smart power meter is connected to HAN but has itself data flow path for server/cloud services

This method gives better options for the smart power meter to communicate with HAN as well as among themselves by wire or wireless media. The figure below demonstrates the case when smart power meters are connected.

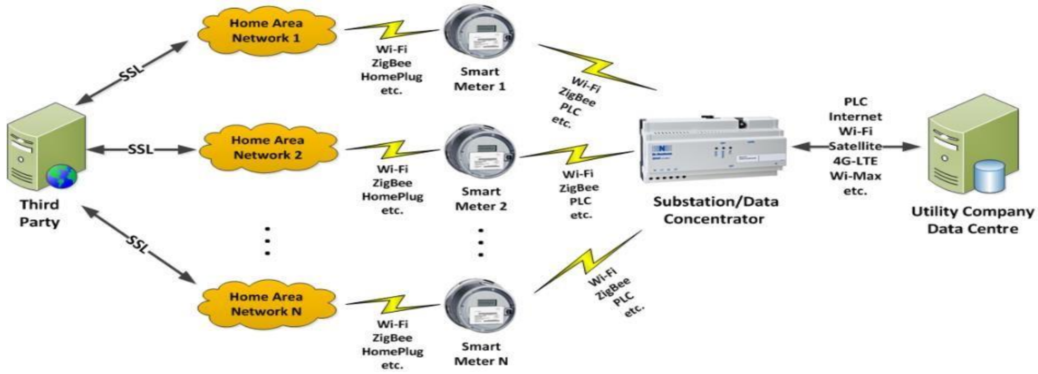


Figure 9. Smart power meter connected to Data concentrators

In this configuration, smart power meters have themselves data paths and separate data plan from stream data of the HAN system. The protocols and communication methods are variety for the user as well as utilities (companies). Data from all the nodes are transferred to the cloud (server) using data concentrator (data collector).

There is a possibility for smart meters can connect to each other in order to create a Neighbor area network (NAN) as the figure below. Yet, this network can be only created through data collectors. By this way, the range of the network is increased.

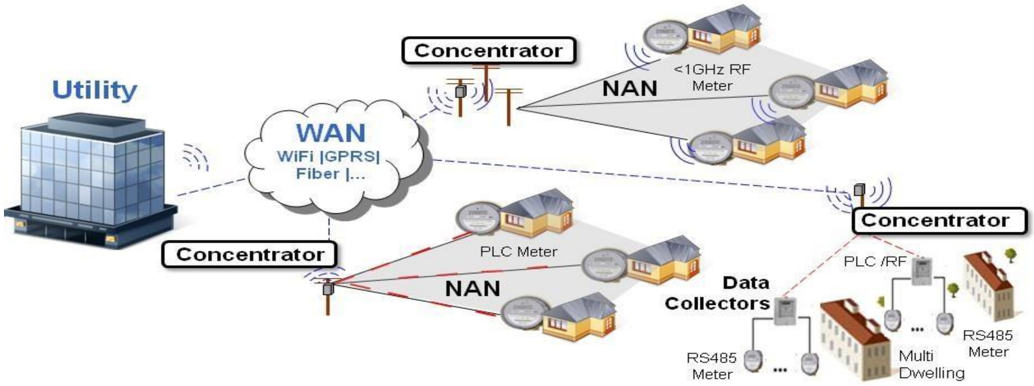


Figure 10. Demonstration of smart power meter configured as sensors networks

Because the data from smart power meter are separated thus it is easier to handle for the application layer.

However, there are still several disadvantages to this method.

- It requests extra layer (data collection) for the network, furthermore, the connections from smart power meters to data collectors are not synchronized. It means each power meter can connect to the data collector by different protocols.
- Customers (users) need an extra connection in order to retrieve the data for their need because the third-party server and utility data center are not connected in some cases. **[2]**

c. Case 3: Smart power meter is connected to AMI by some industrial protocols using for building management.

This study case is inherited from previous study case (Case 2) but it specified by communication protocols for wire media connection.

Protocols such ask DLSM/COSEM, KNX, MODBUS, M-BUS (Meter -BUS), etc. are frequently using in building management (as well as in HAN systems) can be idealized by the figure below.

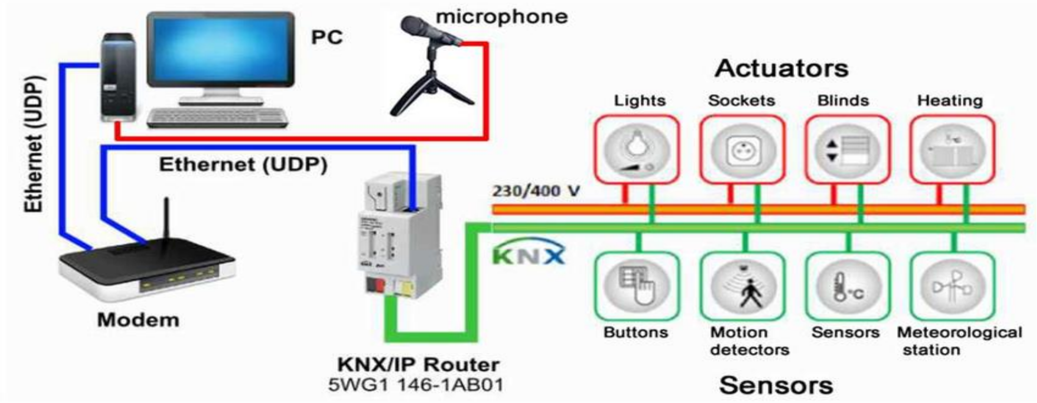


Figure 11. Bus-based connection in HAN network

These protocols provide all functions which necessary for AMI network in order to create more complex networks in a large area as well as fully support multilayer for developing applications. From server side to end-user sides and it can be shown in figure below (demonstration from DLSM/COSEM protocol).

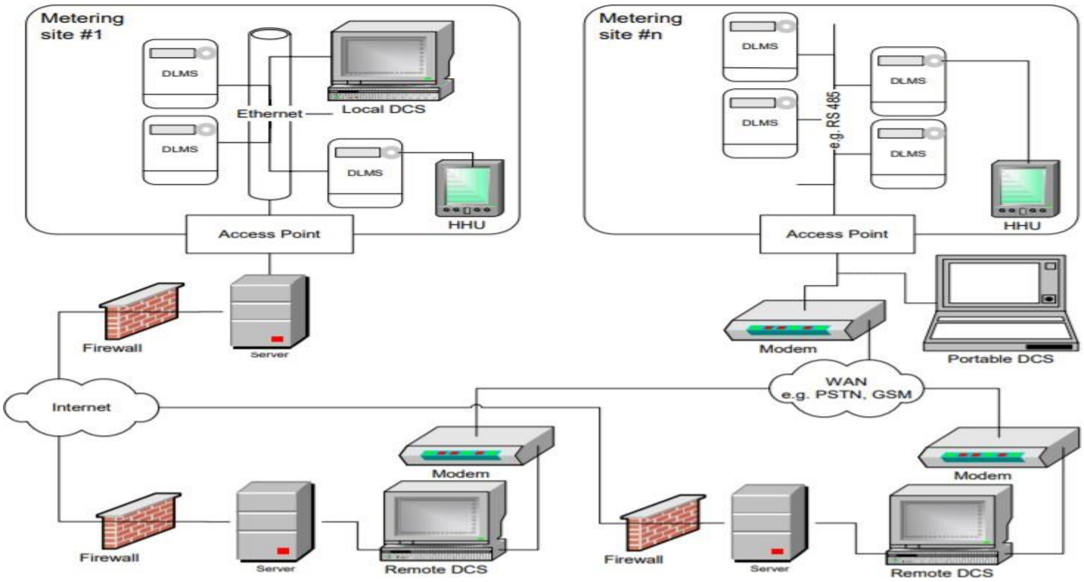


Figure 12. Connection of DLSM/COSEM for remote data acquisitions in AMI [9]

These protocols are also standard and supported by many manufacturers in the AMI industry. Similarly, as in previous study cases, these protocols also have some disadvantages that are can be considered as below:

- Created an extra bus for data exchange between devices causing the extra cost for installation.
- These protocols are good for monitoring building and middle side areas, but it can cause a low-efficiency problem to the bigger network (NAN) because of the high installation cost.
- Each protocol using a different way of working thus they request different way of implementation for HAN network as well as on the side of utilities. For example, in one building where the smart power installed running on DLSM/COSEM, the collected data is encapsulated and sent in a different way and in other building where power meters running on M-BUS causing the different way of data reception. Therefore, it is hard for the utility to synchronize this data.
- From case studies, there are some disadvantages from existing infrastructures

and protocols of HAN systems that are significantly affected by the separation of using smart power meters such as:

- Data measured from smart power meters do not have itself data path. It must be sent either through HAN central controller or to data concentrators/collectors in case of the Bus-based system.
- The expanding and upgrading capabilities of existing infrastructures are not reliable because of differences in technologies (Wireless/Wired, bus-based).
- Installation of the smart power meter is constrained by distance/condition of existing infrastructures.

Chapter 3

Motivation and design

3.1. Problems and motivations

In chapter 2, the overview of the technology of smart power meter, home automation network (HAN) and IoT network are discussed as well as typical application and combination of power meter and home automation network. In this chapter, the future demands based on real-life demands will be studied as well as the limitations of the existing system in electrical power measurement/monitoring. Base on studied problems, the proposed design is come up with solutions for solving the problem and satisfy the demands.

Nowadays, in the Czech Republic, the demands on private cottages or private power solar plants or farms are increased rapidly. First of all, these properties are usually located not in an urban area, people are using cottages for weekend relaxing, solar power plant for harvesting electricity from the Sun and private farms for growing plants/feeding cattle and poultries. Before discussing further, we need to figure out some problems exist with these properties on point of view of the power system.

- For monitoring power consumption in these properties, the “cheapest” solution of the power meter is selected, that means the power meter with basic communication (such as Ethernet, serial optical reader, RS485) is selected. It is not necessary to equip such full-featured power meter (such as with wifi, Zigbee)
- Base on realistic demands, these properties are not located in city/urban area and it means that there are lacking existing infrastructure for Internet or other AMI systems such as DLSM/COSEM or KNX which are using for power monitoring.
- The Internet connection for these properties is not required or on high demands from user/customer since these properties are used for specific purposes. Furthermore, for installing Internet connection for these properties required a significant amount of money and wasting fees for monthly payment since people/owners do not always present there.
- Obviously, the installation of Home automation system is not necessary since the demands for it is really low and of course on the economic point of view it is not optimized since the installation for HAN system is more expensive than for Internet connection.
- Base on topologies of the terrain where the properties are located, it is not an easy and economical solution for deploy such kind of technologies either Internet or HAN in these areas.

Let’s come back to the facts that the requirement for monitoring/reporting power consumption is on high demands for these property and owners/users need a quick, simple, economical saving solution for this. Of course, based on chapter 2 and above analysis, the current technology of HAN or traditional ways of measuring/reporting is not optimized for such kind of these properties.

There are a lot of needs on customer/user sides for these properties:

- The owner wants to monitor the power consumption at his/her properties for billing or safety purposes, but he/she does not want to install such expensive equipment (such a power meter with a wireless connection like GMS)

- The owner has at home already installed Home automation system and he/she wants to connect the power meter from these properties to existing one but her system running on some specified technology such as Zigbee, Bluetooth, or even KNX where the devices need to join the network with their specific requirement.
- How to upgrade the power meter so they can transfer the data to the customer but not using the Internet connection at the properties side since the owner is usually present there?
- Obviously, we can use other technology in AIM systems such as DLSM/COSEM or KNX infrastructures, but these properties are located not in the city and the government/local authorities don't want to spend the money to upgrades these infrastructures.

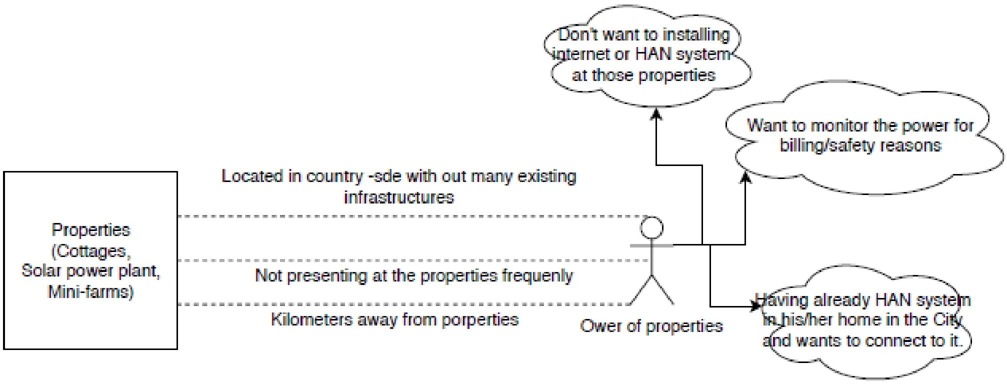


Figure 13. Demonstration of problems in remote power monitoring

The motivation for solving these problems above is to find the affordable solution, which is cheap, simple, easy to install and reliable for monitoring of power consumption.

3.2. Proposed solution and design

In this section, the solution for stated problem will be discussed, the design is tented to solve the disadvantages of existing systems and emphasis on simplicity, cost optimization and compatibilities for upgrading old and existing systems of the power meter.

At this state, there are several options to transfer data from local power meter to the end customer such as:

- Using HAN central controller to collect data and send them over the Internet.
- Using Data concentrator to collect data from existing AMI infrastructure such as DLSM/COSEM and send them over the Internet

Those methods above are required a lot of efforts and costs for installation/operation thus the proposed solution is to upgrade the power meter become a sensor in IoT network and the data collected from power meter will be sent to the IoT gateway and then forward to the Internet. This proposed method exploits the advantages of IoT sensor devices/networks:

- The sensor in IoT network is possible to communicate with their gateways with long range (5-20km).

- In order to upgrade the power meter to become a sensor node in IoT sensor network, it is simple to just use an IoT end device to collect data from the power meter and send them to the IoT gateway. Thus, the effort for installation is saved.
- The data can be collected and sent periodically by the scheduler to IoT network and further to the end user.
- The cost for IoT end devices is much cheaper than other devices for communicating with HAN or AMI system.
- Among available IoT technologies, the LoRaWAN technology is selected for this project because of its features which are simple, free, and easy to deploy. There are many advantages can be used from this design on system point of view such as:
    - Each power meter can be considered as a sensor node in the network with a unique ID, thus the scale of the network is expandable without limitation.
    - Each sensor can be managed by individuals or grouped according to the user.

On the system point of view, the data stream from power meter to end user will be demonstrated in the following figure.

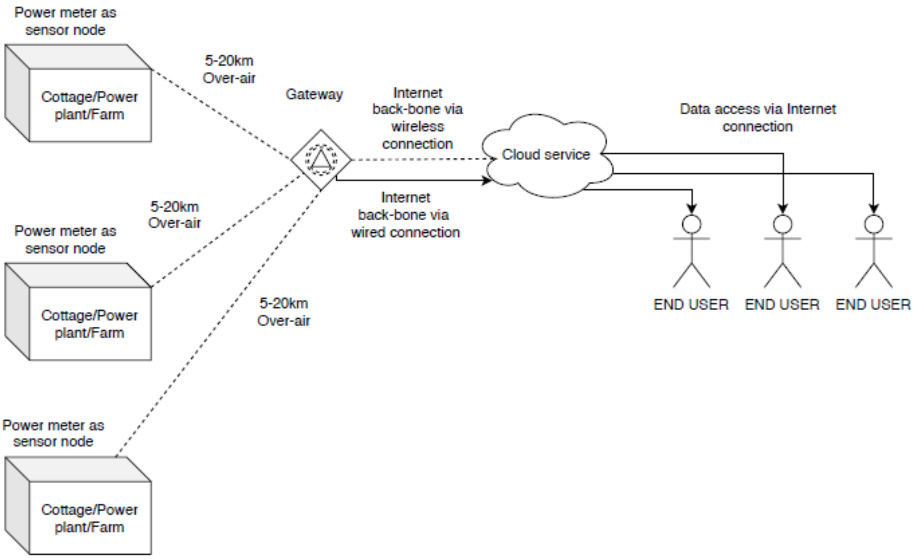


Figure 14. Illustration of multi properties management using the proposed design

The gateway can be privately installed in a location where the internet connection is way easier to archive or can be used from a service provider with monthly payment is cheap as 2% of normal internet connection.

In detail, the proposed design is invoked with the following components, the detail implementation of the design will be discussed in the next chapters. The figure below briefly describes the overview of the system and the data flows on devices.

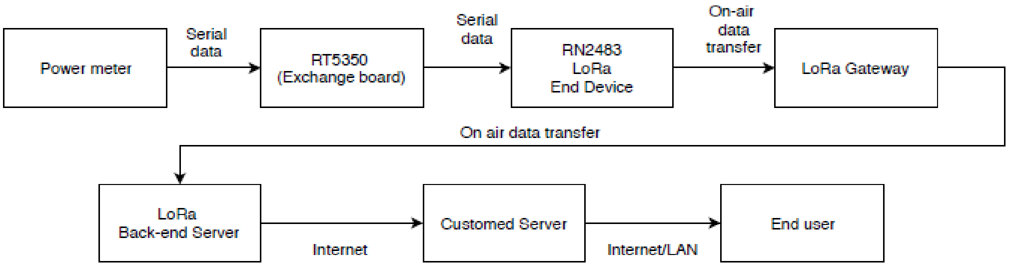


Figure 15. Overview of design structure

From the figure, we can see that the idea is to upgrade the power meter with LoRa technology by using an exchange board and LoRa communication system with the scheduler for periodically send data to the LoRaWAN network. Then from the gateway, these data are transferred to the cloud services through the Internet and user can retrieve the data using call back API on their customized server. The customized server then prepares the data directly to the user or any kind of HAN system using their specification.

The core idea behind the solution is to find the way of streaming data from power meter to end user HAN system through several medium and protocols.

Chapter 4

LoRaWAN technology and application

4.1. Introduction to LoRaWAN technology

In this section, the brief study about LoRaWAN technology will be considered as a reference to implement the proposed design. The LoRa technology is term indicates a set of hardware, software and communication protocol which are developed for IoT.

LoRaWAN is a media access control (MAC) protocol for wide area network. In other word, LoRaWAN defines the network protocol and architecture for communication of devices in the network. The terminology of LoRaWAN is based on a combination of three kinds of devices which are listed below. [3]

- End devices (Nodes) are made from embedded low power devices with installed LoRa protocol. Their responsibility in the network is aimed for collecting data and sending collected data to the gateway.
- Gateways are devices with LoRaWAN protocol installed and collect data from End devices or/and send data to End devices. Besides that, a gateway can connect to the Network servers using Internet connections such as 3G/Ethernet/Wifi Backhaul.
- Network server’s response for routing data from End Devices to the right Application and back.
- Application server’s response for processing of collected data from end devices and delivered them to appropriated applications.

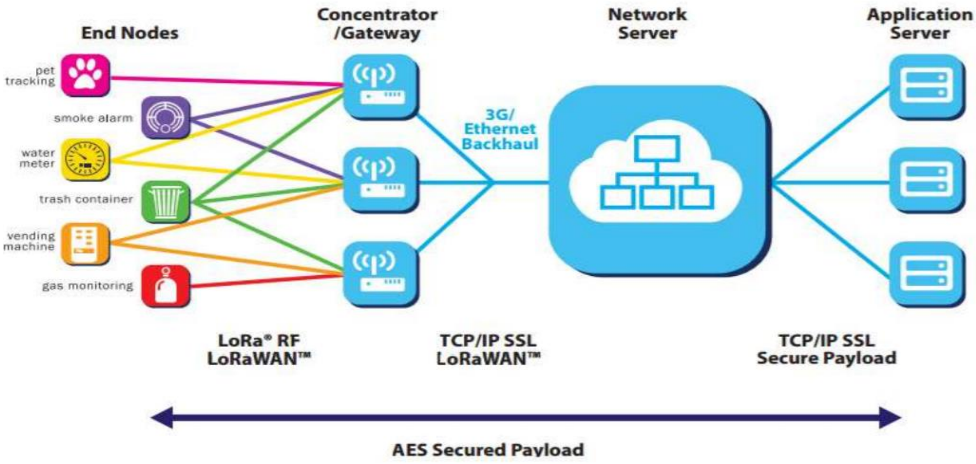


Figure 16. Overview architecture of IoT network

On the hardware point of view, the LoRa technology using the following specification [4]:

- Frequency modulated (FM) chirp
- Operating frequency 443/868/925 MHz (depends on regions)
- 125 kHz Band Width
- Transmission rate 250-5470 bps
- Transmit power less than 100 mW
- Rage up to 20 km (open area)

Following are the functions of **LoRaWAN Physical Layer** (PHY) [5]:

- Physical Layer constructs the frame in order to transmit payload from MAC layer over the RF link.
- It inserts PHDR, PHDR_CRC, preamble, and CRC for the entire frame. CRC field is available in uplink message only.
- As a preamble specific constant sync words are used based on modulation technique either LORA, GFSK or FSK. This preamble will help in synchronization at the receiver as it is known to the receiver.
- PHY layer uses specific RF bands as per countrywide requirement.

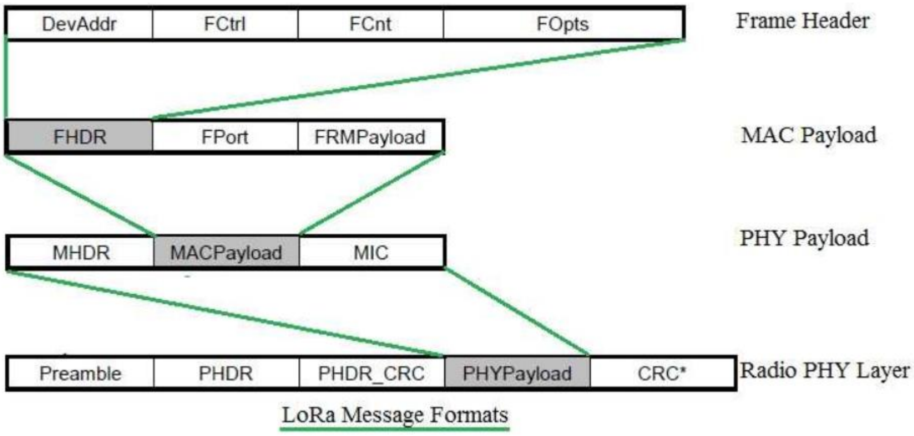


Figure 17. LoRaWAN message formats

On the software and communication protocol the LoRaWAN can be seen as the following figure:

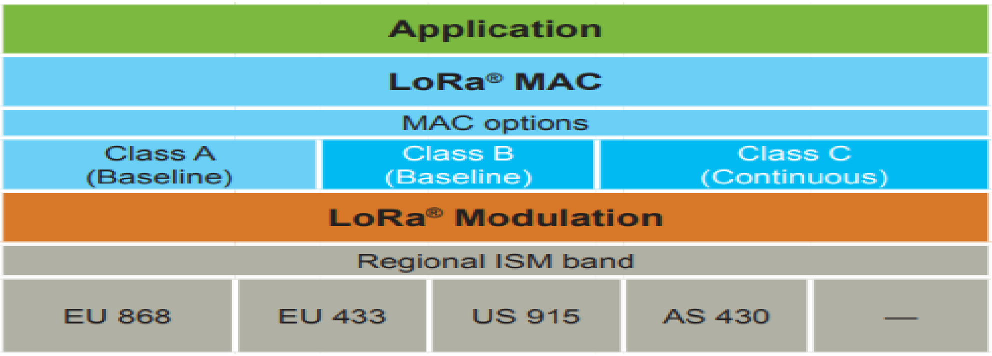


Figure 18. OSI representation of LoRaWAN [5]

LoRaWAN MAC is a core part of LoRaWAN protocol which defines the frame format, mode of operation and network properties. There are three classes of LoRaWAN which is used for defining the mode of operations. The figure below illustrates the characteristics of each class in uses [5]:

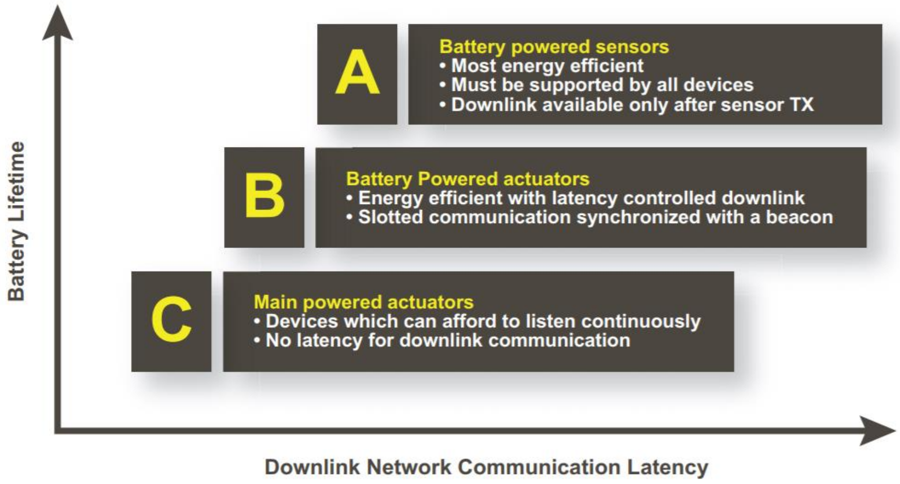


Figure 19. Operation class of LoRa and their characteristics

Every sensor node in LoRaWAN network needs to register with LoRaWAN gateway in order to communicate with the gateway and this activation is done by using LoRaWAN MAC protocol stack. The LoRaWAN MAC provides two methods for activation:

ABP Activation [6]:

- End-device address (DevAddr): identifies the end-device within the current network.
- Forwarding Network session integrity key (FNwkSIntKey): Uplink MIC key.
- Serving Network session integrity key (SNwkSIntKey): Downlink MIC key
- Network session encryption key (NwkSEncKey): Encryption key between ED and Network Server (commands).
- The application session key (AppSKey): Encryption key between ED and Application Server (data)

Over-The-Air-Activation (OTAA) [6]:

An alternative to static activation configuration, join procedure prior to participating in data exchanges with the Network Server. An ED has to go through a new join procedure every time it has lost the session context information. Required information in the ED prior to OTAA:

- JoinEUI: global application ID in IEEE EUI64 address space that uniquely identifies the Join Server that is able to assist in the processing of the Join procedure and the session keys derivation.
- DevEUI: Globally unique device identifier in IEEE EUI64 address space.
- AppKey: root AES-128 encryption key specific for the end-device that is assigned by the application owner to the end-device and most likely derived from an application-specific root key exclusively known to and under the control of the application provider. Since all end-devices end up with unrelated application keys specific for each end-device, extracting the AppKey from an end-device only compromises this one end-device.
- NetworkKey: root AED-128 key specific to the end- device but provided by the network operator.

4.2. LoRaWAN frequency planning and regulations

In section 4.1, the general architecture of LoRaWAN is considered from a network point of view. In this section, the detail discussion of LoRa physical layer is studied. The section describes the important characteristics of LoRa physical which are fundamental keys for designing networks such as the size of the network or transmission qualities and capabilities.

4.2.1. LoRa characteristic and parameters

LoRa is a chirp spread spectrum modulation which uses frequency chirps with a linear variation of frequency over time to encode information. It encodes symbols into one of the multiple signals of increasing (up-chirp) or decreasing (down-chirp) frequencies. Therefore, the frequency offsets between receiver and transmitter are equivalent to timing offsets and it will be easily eliminated in the decoder. Beside modulation, a LoRa transmission invokes following important keys parameters [7]:

- Bandwidth (BW) defines the width of the radio frequency being used.
- Carrier Frequency (CF) defines medium frequency.
- Coding Rate (CR) defines the Forward Error Correction (FEC) rate(s) is
- being used by LoRa device.
- Spreading Factor (SF) defines the ratio between the symbol rate and chip rate.
- Transmission Power (TP) defines the power used for transmission and will be used for calculation of the link budget.

Bandwidth (BW) [8]

LoRa supports three scaleable BW settings of 125Khz, 250Khz, 500Khz, as shown in figure 20 below. The higher bandwidth gives a higher data rate (thus a shorter time on air), however the lower sensitivity. On the other hand, the low bandwidth gives lower data rate but better sensitivity.

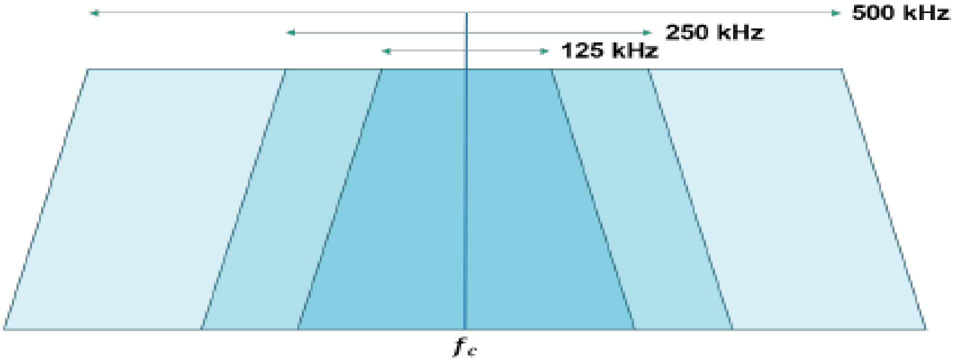


Figure 20. LoRa Bandwidth Corresponds to the Double Sided Transmit Spectrum Bandwidth [8]

Spreading Factor (SF) [8]

LoRa uses multiple orthogonal spreading factors (range from 7 to 12), this parameter decides the trade-off between data rate and rage. The higher spreading factor can increase the rage but decreases the data rate. On the other aspect, the higher spreading factor increases the Signal to Noise Ration (SNR), thus the sensitivity and range are affected. Similarly, like BW the higher spreading factor prolongs the time on the air of the packages. The spreading factor indicates how a symbol is representing by chips, thus the number of chips per symbol is calculated as 2^{SF}. The figure 21 below represent the process of encoding the symbol to bit using SF.

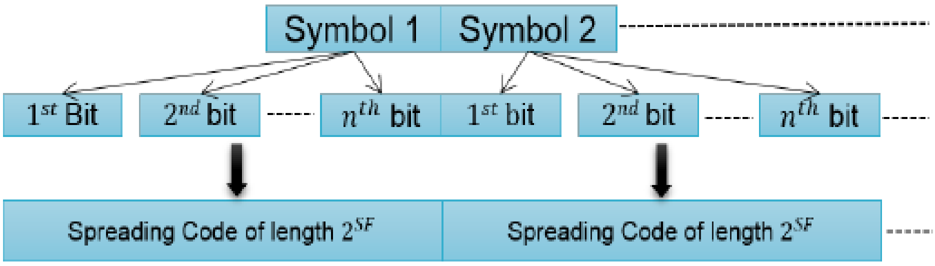
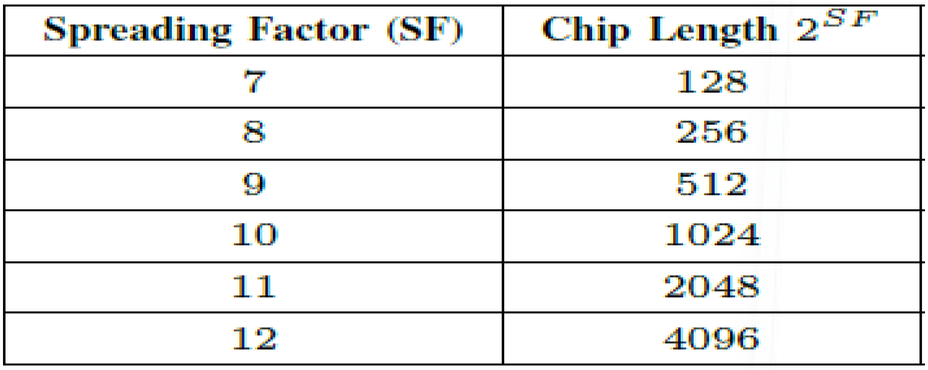


Figure 21. Spreading factor on the symbol of LoRa [8]

Each increase in SF influences the transmission rate thus the power consumption. Figure 22 below shows the relationship between SF and Chip length.



Spreading Factor (SF)	Chip Length 2^{SF}
7	128
8	256
9	512
10	1024
11	2048
12	4096

Figure 22. Spreading factor and corresponding chip length of LoRa [8]

As discussed, the bandwidth (BF) and spreading factor (SF) have an effect on the data rate, the graph below represents the relationship among BF, SF and data rates.

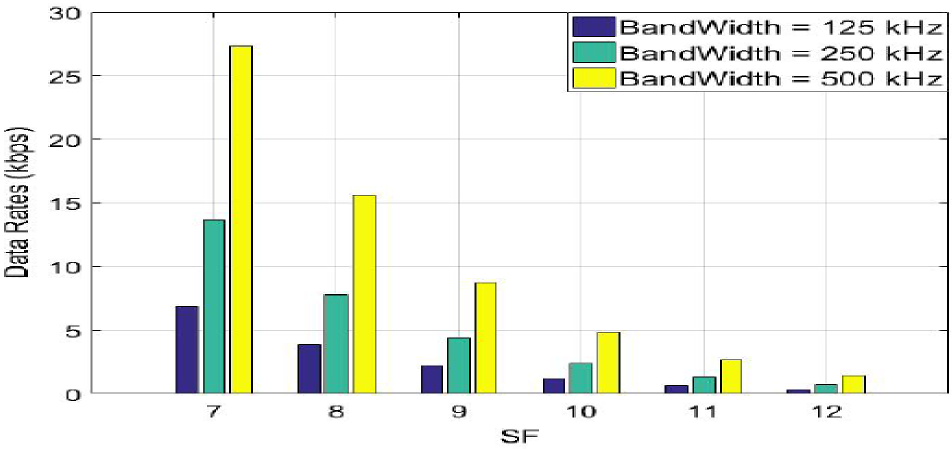


Figure 23. Data rates in LoRa with Different spreading factors and bandwidth values (Coding rade = 0) [8]

Coding Rate (CR) [8]

As mentioned, the coding rate defines the Forward error corrections (FEC) which are used for optimizing the receiver sensitivity. LoRa offers CR values from 0 to 4, where 0 means no FEC. In detail, the term CR define is used for determining the number of bits used for useful information, total output bit and redundancy bit. For example, if we denote the k representing a number of useful information, n is a total number output of bit from the encoder. Then, n-k is the number of redundancy bits. The redundancy helps the receiver to detect and correct errors in the messages, however, it also reduces the effective data rates.

The impact of Transmission parameter selection

Combination of listed parameter above generates quality of LoRa transmission. The bitrate is determined by SF and BW and CR defines the symbol sized of a package and together with payload decide the time on the air of a transmission. In the following section, the calculation of time on air and how it affects the transmission will be explained parallelly with regulations of frequency planning used in the EU.

4.2.2. Regulations

One of the important aspects of LoRaWAN in the application is planning and regulations. In the Czech Republic, the frequency plans and regulations are acquired by EU863-870 frequency plan. The LoRaWAN is running on the RF 868MHz which is a public bandwidth European Low Power Network (LPWAN) and the norm(documentation) ERC-REC-70-2E regulate this bandwidth. In detail, the regulations for this bandwidth are based on two main restrictions [9]:

- Transmission power: It is defined as the maximum power of an emitter can use on the channel when it is communicating is about 25mW (14dB).
- The duty cycle: It is defined as the maximum ratio of time on the air per hour and for LoRaWAN is limited to a maximum of 1% for all of 8 channels (EU region). That mean we can configure different duty cycle for each channel. However, the sum of all duty cycles of all channels must not exceeded 1%. Particularly, in this project, the default setup of RN2483 is used. The RN2483 is set up with first 3 channels by default (868.1, 868.3, 868.5 MHz) with data rates 0-to-5 and 0.33% duty cycle for each. The other channels are set with very low duty cycles.

Duty Cycle [10]

The duty cycle is a mechanism for limiting device access to radio frequency. A duty cycle restricts the amount of time each device can be transmitting.

For example, if the device is limited to 1% means, if it transfers for 1 second then it needs to wait next 99 seconds for the next transmission (if we consider the transmission of 100 seconds). In particular, the 1% of duty cycle meaning that only 36s per hour is accepted for communication among devices.

The relation of Time on Air (ToA) and Duty Cycle is calculated by flowing formula:

$$T_{off} = \left(\frac{TimeOnAir}{DutyCycle}\right) - Time\ On\ Air \quad (1)$$

Where,

TimeOnAir = radion transmission time (s)

DutyCycle = sub-band duty cycle limitation (%)

T_{off} = Time that transmitter must be slient.

The restriction of the duty cycle defines the time on air (ToA), thus it restricts the data packages size (payload) and other parameters selections such as BW, SF, CR and finally the transmission power (TP).
In other word, the constraints between payload, parameters selection, transmission power and regulations defined how the transmission should behave. Therefore, during design, we need to consider these factors for optimized the transmission among devices.

Time On Air (ToA) [10]

The calculation of the time on air is important for fitting the design with the regulation of radio transmission thus in this section we discuss how to calculate the Time On Air. The time on air is calculated based on the total length of the package which contains several elements. The typical package of LoRa is shown as the following figure.

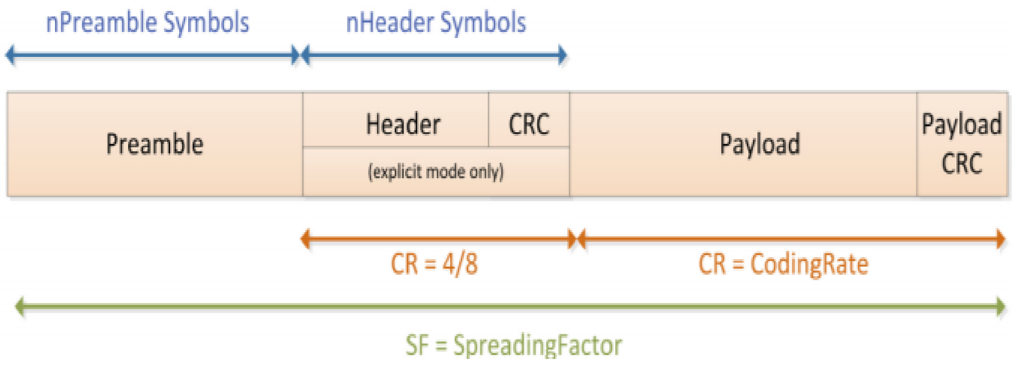


Figure 24. The frame format of LoRa package

Each of the quantities listed in the figure above such as preamble Symble, nHeader Symbols, CR, SF are used for calculating total time on the air of the transmission.

The general formula using for collection time of air of a package is shown as the following formula:

$$T_{package} = T_{preamble} + T_{Payload} \quad (2)$$

Where,

$T_{package}$ is total time of the package or Time on Air

$T_{preamble}$ is time for preamble

$T_{Payload}$ is time for payload

The preamble time is calculated by the following formula:

$$T_{preamble} = (n_{preamble} + 4.25) \times T_{sym} \quad (3)$$

Where,

$T_{preamble}$ is time for preamble

$n_{preamble}$ is length ofthe preamble

$the\ T_{sym}$ is symbol duration

The symbol duration is calculated as the following formula:

$$T_{SB} = \frac{2^{SF}}{BW} \quad (4)$$

Where,

T_{SB} is symbol time duration

SF is a spreading factor

BW is bandwidth used

The payload symbol time is calculated as the following formula:

$$T_{payload} = payloadSybNb \times T_{SB} \quad (5)$$

And the last parameter payload symbol length is calculated ($payloadSybNb$) as:

$$payloadSybN = 8 + \max(ceil\left(\frac{8PL-4SF+28+16CRC-20H}{4(SF-2DE)}\right)(CR+4), 0) \quad (6)$$

Where,

PL is number of payload byte

H: 0 when the header is enabled and 1 when there is no header

DE: 1 to enable data rate optimization and 0 for vice versa

CR: coding rate

The detail of parameter selection and calculation for the project are shown in the INDEX part of this thesis.

4.3. Interfacing the power meter with RT5350F

The interfacing of RT5350 board (the exchange board) with a power meter is done through optical to serial adapter which converts the optical signal from power meter into serial data (UART) for exchange board. Since it is across flat-form communication thus the exchange board is implemented in such a way that it can satisfy the following requirements:

- The power meter with optical port running on IEC 62056-21 Communications Protocol thus the serial data transferred from power meter need to have received according to the protocol.
- The IEC 62056-21 protocol using OBIS codes for indicating the quantities and corresponding values, therefore the data recorded into the exchange board should be prepared with full information for applications later.
- The reading of power meter needs to be scheduled (by minutes, hours or days)

These requirements will be explained in detail in the next sections, on the other hand, the general structure of the communication line between the power meter and the exchange board is shown in the figure below:

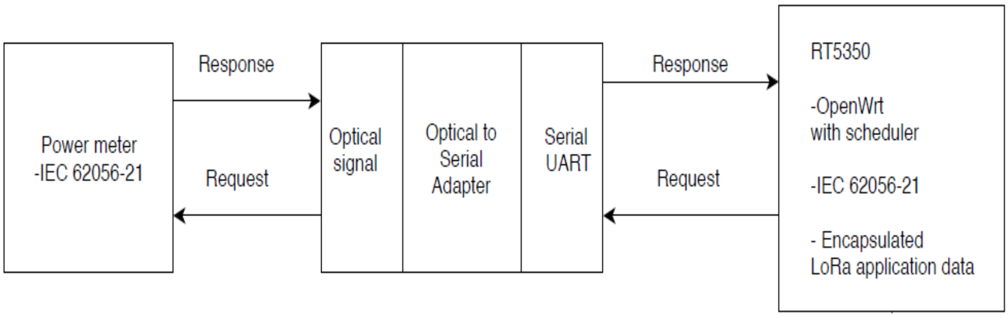


Figure 25. Interfacing of the power meter with exchange board RT5350

IEC 62056-21 protocol is Electricity metering – Data exchange for meter reading, tariff and load control which is a part of IEC 62056 protocol. IEC 62056-21 is ASCII based communication, defines physical properties, character transmission, data transmission protocol for electricity metering and it specified for direct local data exchange. The local exchange data can be between meters to meters or meters to other devices. In this project, for local data exchange between the power meter and the exchange board RT5350F, the parts of IEC 62065-21 standard are applied. In detail, the IEC 62065-21 standard define several modes for reading out the data from tariff device named from A to E. The power meter used in this project support the readout data in mode C. An example of read-out phase for power meter according to IEC-62065-21 mode C is shown in the figure below. [11]

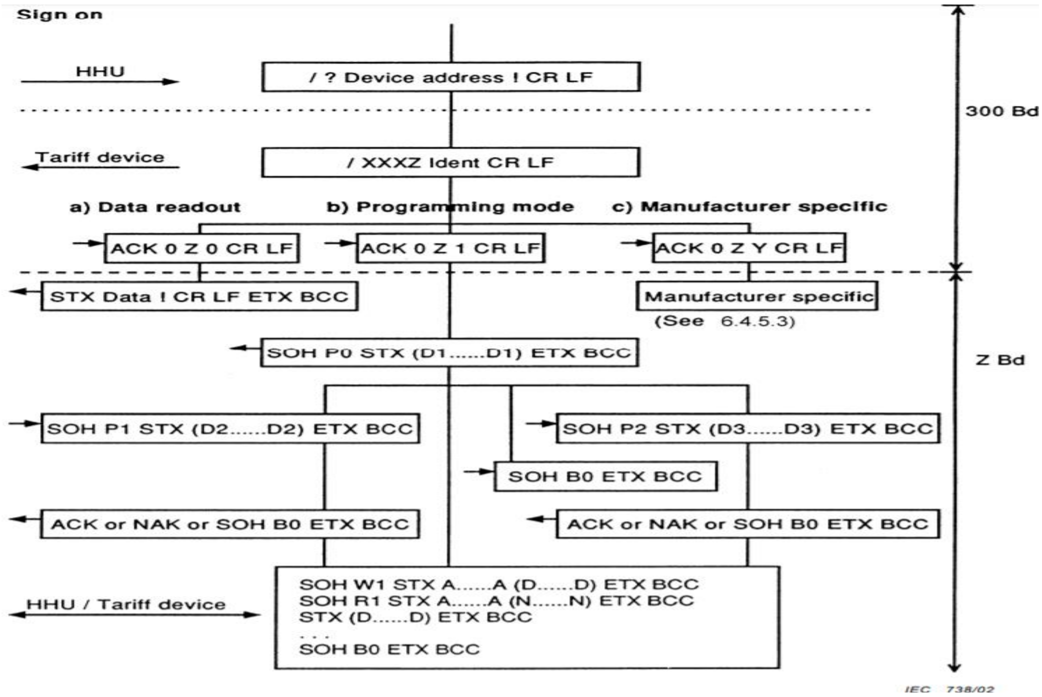


Figure 26. Network communication diagram of IEC-62065-21 standard [12]

From the figure above, after receiving the sequence "ACK 0 Z 0 CL LF" the tariff device will respond with a predefined data set which are compliance with OBIS code. This predefined data set is programmed by the manufacturer. As the primary baudrate for this mode is set to 300Bd, therefore if the character "Z" in the sequence above is set to 0 then the readout sequence will be performed with primary baudrate. The detail process of readout for the power meter in this project is presented in the INDEX part of this thesis.

The data read out from power meter are formatted by using the OBIS code, the OBIS code defined the quantities and values. The code consists of (up to) 6 group sub-identifiers marked by letters A to F. All these may or may not be present in the identifier (e.g. groups A and B are often omitted). In order to decide to which, group the sub-identifier belongs, the groups are separated by unique separators [12]:

A-B:C.D.E*F

- The A group specifies the medium (0=abstract objects, 1=electricity, 6=heat, 7=gas, 8=water ...)
- The B group specifies the channel. Each device with multiple channels generating measurement results can separate the results into the channels.
- The C group specifies the physical value (current, voltage, energy, level, temperature, ...)
- The D group specifies the quantity computation result of a specific algorithm
- The E group specifies the measurement type defined by groups A to D into individual measurements (e.g. switching ranges)
- The F group separates the results partly defined by groups A to E. The typical usage is the specification of individual time ranges.

The exchange board is running lightweight operating system named as OpenWRT which supports task scheduling using "cron" application, therefore the scheduled read for reading out data from a power meter is performed by the following table.

Table 1. Scheduled read- out of data and quantities

Quantity	OBIS	Units	Custom scheduled read-out
Total imported power	1.8.0	kWh	Every 10 minute*
Total exported power	2.8.0	kWh	Every 10 minute*
Current phase 1	31.7	Amp	Every 1 hour*
Current phase 2	51.7	Amp	Every 1 hour*
Current phase 3	71.7	Amp	Every 1 hour*
Voltage phase 1	32.7	V	Every 1 hour*
Voltage phase 2	52.7	V	Every 1 hour*
Voltage phase 3	72.7	V	Every 1 hour*
Frequency	14.7	Hz	Every 1 hour*

Table explanation:

- The quantities used in the table are selected from many others measured from the power meter. It is possible to read, record, and transfer more data indeed. However, the more we want to transfer, the more calculation for parameter selection is needed.
- (*) The custom Scheduled read out indicate the time interval for the exchange board reads the data from the power meter. Therefore, the quantities such as current and voltages of phases are instantaneous values. Power values indicate total power consumption until the moment of the read-out phase. Overall, these time intervals do not represent the time of power meter, but they represent the time read-out of the exchange board.

Finally, the packed data format for LoRa application is encapsulated as in the following structure

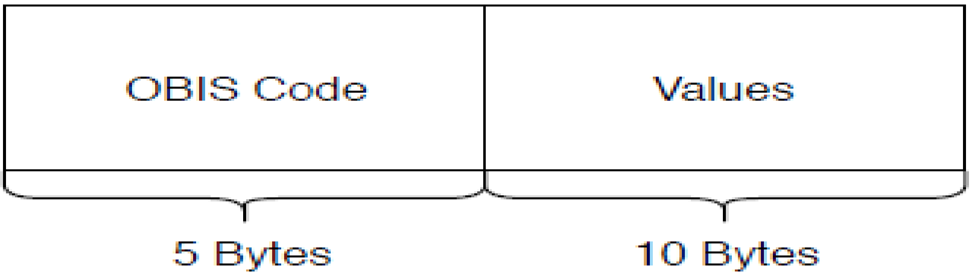


Figure 27. Format of data read from the power meter

These packed data will be used as the data for the application layer in the OSI-based model of LoRa protocol (refer to section 4.1). The next sections described the encapsulation of application data into LoRa protocol and transmission of data over LoRa.

4.4. Interfacing LoRa module with RT5350F

The second functionality of the exchange board is to forward the collected data from power meter to the LoRa module and then transmit them to the L. In order to do it, the connection between exchange board and LoRa module is established using serial communication UART, the connection is shown in the figure below.

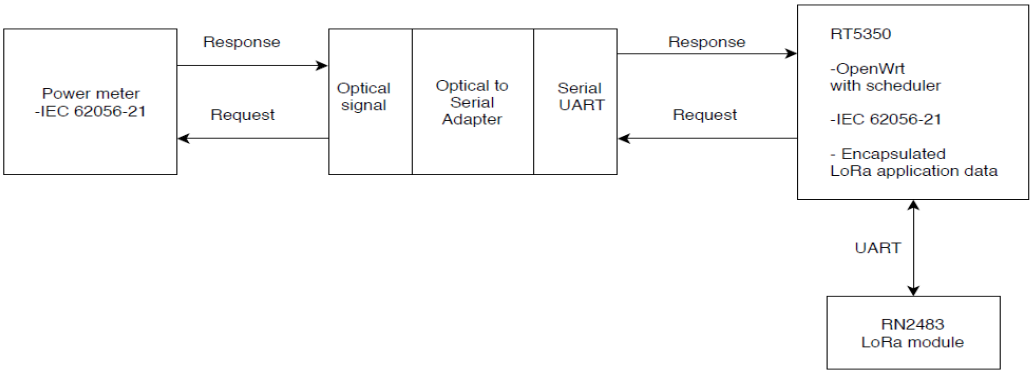


Figure 28. Interfacing of LoRa module with exchange boar RT5350F and power meter

The configuration for LoRa module is done through UART connection from the exchange board with specific AT command and baud rate is 4800bps. The following configurations are set up on the RN2483 chip:

- Frequency: 868 MHz (EU band)
- Join method: ABP joins with a private API key and a Network key.

At this stage, the data or value measured from the power meter is stored on exchange board and the board will perform the scheduled sending data over LoRa to the gateway by encapsulating the data into LoRa frame. The structure of the frame is described in section 4.1 above. The LoRa gateway is prepared to accept data and then forward the data to a customized server. The process of the transmission is shown in the figure below.

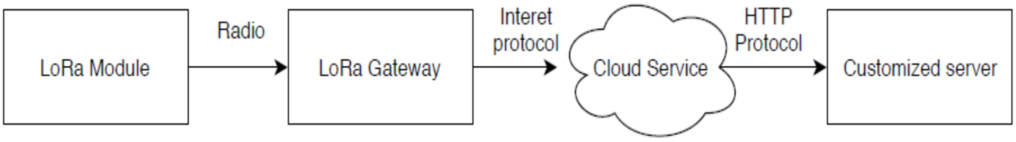


Figure 29. Data flow in the system as a sensor in IoT network

The scheduler of the exchange board will schedule the sending time and sending sequence since the limitation of sending data of LoRa network.

The customized server responses for preparing the reception of incoming data from cloud service and store them in a proper way for next application which is KNX and will be presented in the next chapter. The power meter is upgraded/configured as a sensor node in a LoRa network and at the customized server the data from cloud service is shown in the index part of this thesis. From the data, some important information is collected to process for future application such as EUI (End-Device unique identifier), port number, frequency, date and time, and the most important is core data in hex formatted.

The concept for managing the power meter as a sensor in LoRa network (or IoT network in general) is to use the EUI of each device and bind the EUI device to a specific identifier of applications. For example, if there are several power meters on one property like a big cottage has also solar power plants then it might have several power meters installed for each unit. Then each power meter on the property (sensor network) will be identified by their UID. The demonstration of the user's cases can be seen as the following figure.

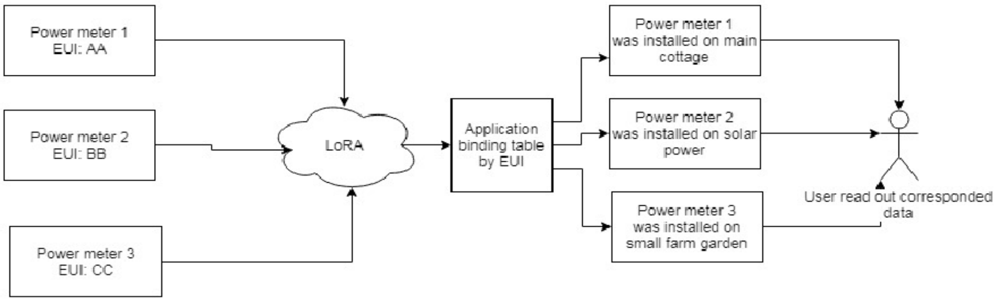


Figure 30. Multiple power meter management using EUI of LoRa

In this project, there is only one power meter used, however base on this idea, it can be applied to implement several devices in the KNX network, and it can be extended to other type of meters (such as gas, water, etc).

Chapter 5

KNX and application

5.1. Introduction to KNX

KNX, also known as Konnex, is an open international building control standard. It is a successor of three previous standards, European Home Systems Protocol (EHS), BatiBUS, and the European Installation Bus (EIB). The KNX standard is administered by the KNX Association which was founded in 1990. As of June 2010, the KNX Association has over 200 manufacturing members. [13]

The KNX is technology for home automation using bus topology to construct the network, each device on the bus is able to communicate with each other independently without a central control system. The communication is established by using telegram transmitted on the bus. The mechanism for devices in the bus is considered as 'listen to mechanism', that means the devices on the bus listens on the bus if its unique identification address is called and start to response to the incoming address. The topology of the bus communication is shown in the following figure:

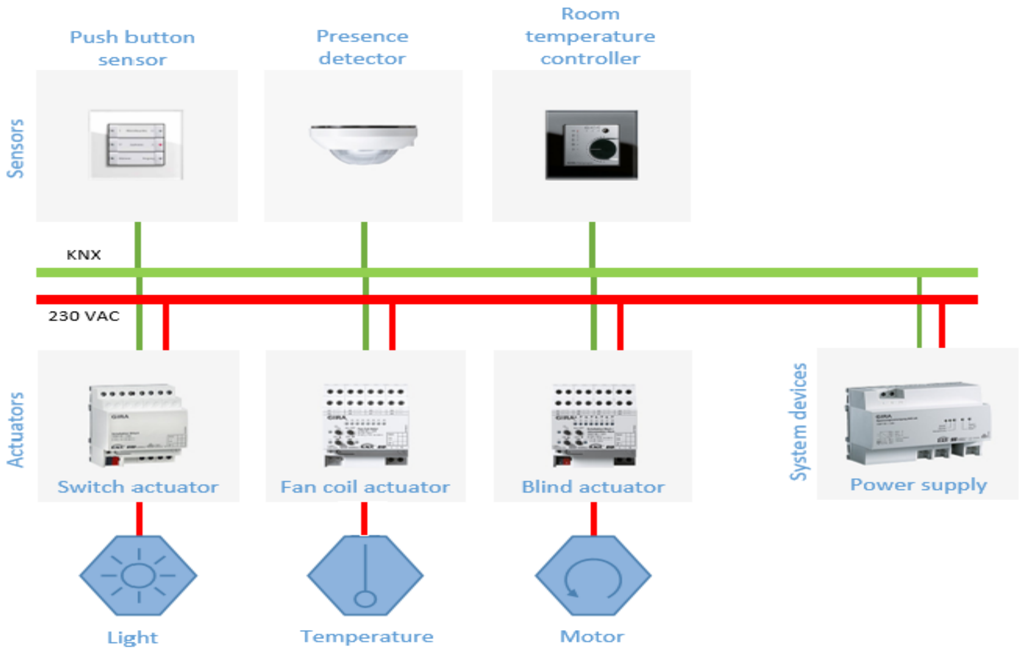


Figure 31. Demonstration of KNX bus network

The network architecture is structured on three levels which consist of Backbone (area line), Mainline and Lines with details are listed as below [14]:

- The area line is the backbone of the network. The subnetwork address (area line) is 0.0 (zero.zero). 15 area couplers (Ac) can be connected to the area line, in addition to bus devices (not shown), whose number is determined by subtracting the number of area couplers from 64.
- 15 main lines can branch off from area line 0 by means of area couplers. The area couplers used to establish the main lines have physical addresses from 1.0.0 to 15.0.0.

- Each main line can accommodate 15-line couplers (Lc), in addition to bus devices (not shown) whose number is determined by subtracting the number of line couplers from 64.
- 15 lines can branch off from each main line via line coupler. The line couplers used to establish the lines from main line 1 have physical addresses from 1.1.0 to 1.15.0.
- Line couplers from main line 15 have physical addresses from 15.1.0 to 15.15.0.

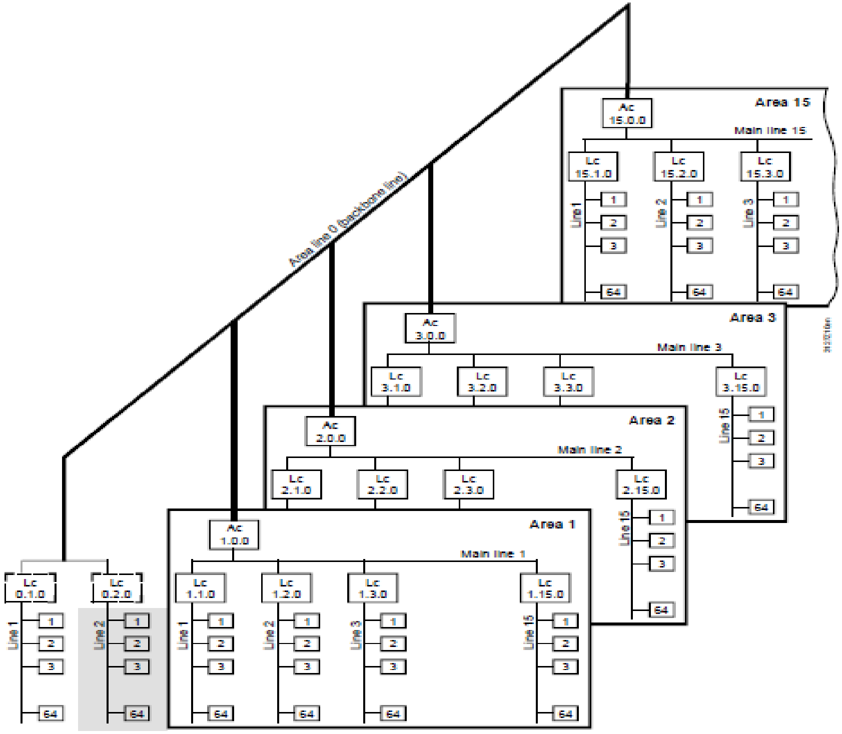


Figure 32. Full-scale of KNX network architecture [14]

An important aspect of KNX is frame format which shall be covered in this section since later the implementation of KNX device for HAN application will be explained in the next sections. The frame is later considered the application layer in the KNX server-client model and its structure is shown in the figure below.

octet 0	1 2	3 4	5	6		7	8 .. N - 1	N ≤ 22
Control Field	Source Address	Destination Address	Address Type; NPCI; length	TPCI	APCI	data /APCI	data	Frame Check

Figure 33. KNX data telegram

- ***Control Field*** determines the frame priority and distinguishes between the standard and extended frame.
- **Individual *Source Address*** and individual (uni-cast) or group (multi-cast)
- ***Destination Address*** the destination address type is determined by a special field.
- ***Transport Layer Protocol Control Information*** (TPCI) controls the transport layer communication relationships, e.g. to build up and maintain a point-to-point connection.

- ***Application Layer Protocol Control Information*** (APCI) can tap into the full toolkit of Application Layer services (Read, Write, Response, …) which are available for the relevant addressing scheme and communication relationship. Depending on the addressing scheme and APCI, the standard frame can carry up to 14 octets of data.
- ***Frame Check*** helps ensure data consistency and reliable transmission.

5.2. KNX-IP stack

Various communication media and transmission methods can be used in the KNX system, either KNX Twisted Pair (KNX TP), KNX Powerline (KNX PL) uses the existing 230 V mains network, KNX Radio Frequency (KNX RF) communication via radio signal or KNX IP – communication via Ethernet/WiFi. In this section, the detail explanation of KNX IP is shown as a demonstration for the next section of interface KNX server for HAN system. The reason to use KNX IP for the project is that the KNX-IP is common for most of the KNX system and it can be implemented across the Internet, so the potential of its application is high.
The use of KNX IP in the KNX system is by replacing the line couple with KNXnet/IP router which can be seen as in the figure below.

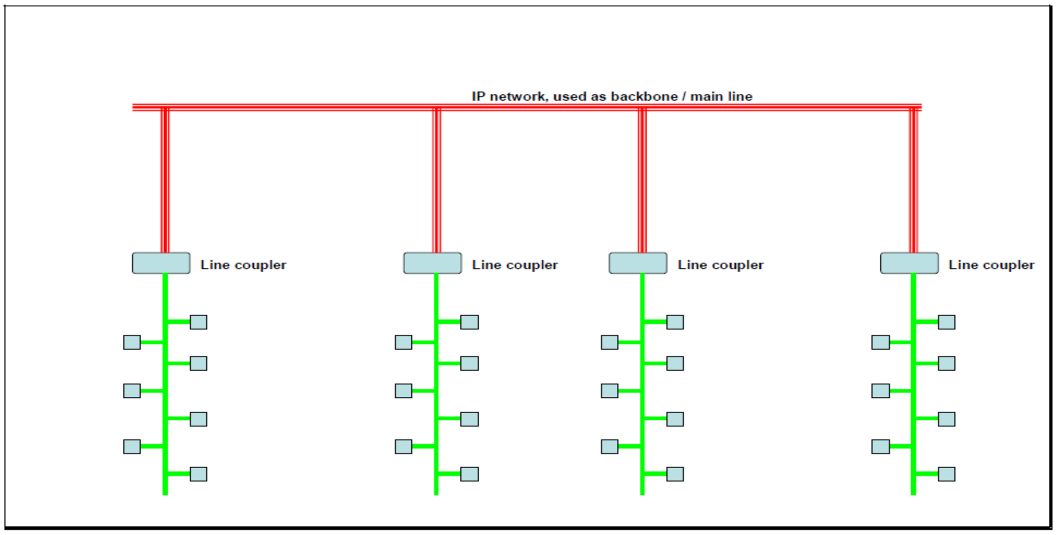


Figure 34. Demonstration of KNX IP network

The IP communication in KNX can be explained using the OSI reference model and using UDP protocol for establishing a connection between two devices which can be shown in the figure below.

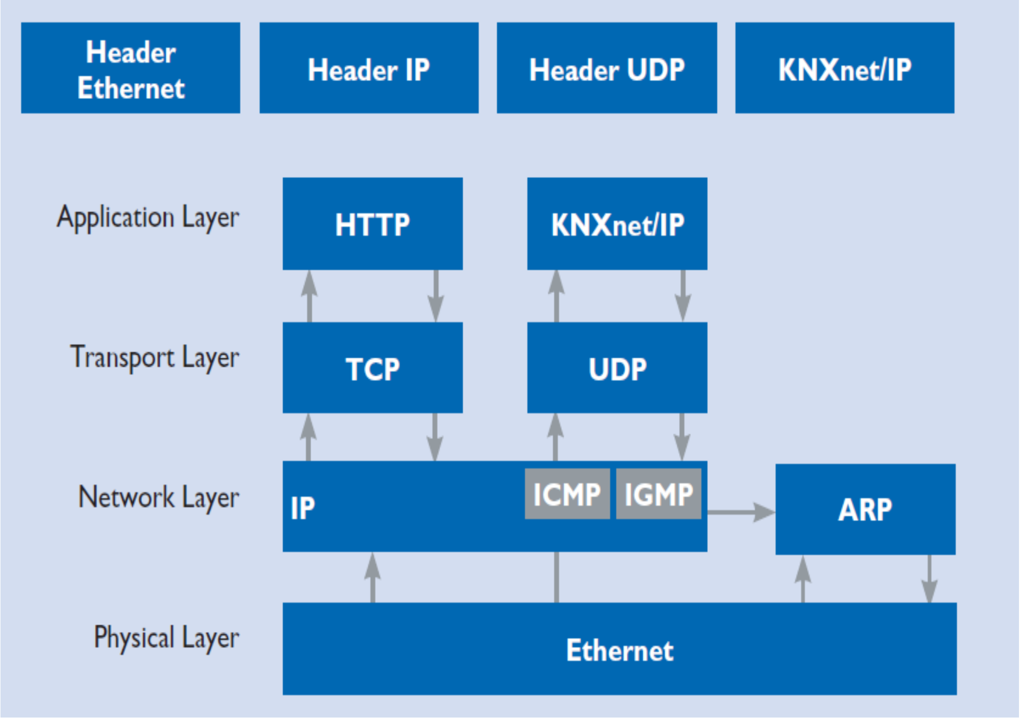


Figure 35. OSI model representation of KNX IP

There are two modes of connection between KNX IP devices, those are Tunneling IP and Routing IP.

Tunneling is used when two devices want to communicate directly to each other because the physical IP address is assigned to each device and the implementation on the software side is done in such a way that it will send only the packets to specific IP address.

Routing is used for simultaneous, connectionless transmission of a KXN device to several other KNX devices. This is equivalent to group communication in other networking protocol. This routing method invokes the KNX router in the transition line. The packets are sent as multicast to multiple IP addresses.

5.3. Interface KNX server for HAN application

The section describes the interfacing of data prepared on a customized server to the KNX network. The aim of this implementation is to demonstrate the solution for the end user in the home automation network who is considered as an end user. As described in the previous sections, the devices in the KNX bus communicate with each other by listening on the bus data. However, to clarifying the working model of the power meter in the KNX network, the idea of “server” and “client” is introduced. In details, the virtual power meter (the data prepared at the customized server) is considered as a sensor in the network, thus, the responsibility of it is defined as a device to answers all the request from other devices for the values which is measured. On the other side, the end user device (ex: a tablet with KNX software) will send the request to the sensor for retrieving needed data. By those reasons, the model of “server and client” is a good model to simulate the operation of power meter as a sensor in the KNX network with KNX IP communication.

The power meter is installed kilometers away from the end user, therefore in this section, the power meter is denoted as a server. The term “server” is indicating the implementation of power meter simulated as sensor device in KNX where data collected from a real power meter is prepared in such a way that it can answer any request from the client device. The client device is implemented as a value reader for sensors in the KNX network where it generates the requests to the server and receives corresponded values. Before going into detail explanation of server and client, the overview structure of their model is shown in the figure below.

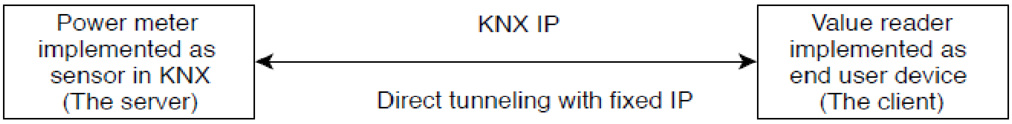


Figure 36. The client-server model of KNX implementation

As described above, the server is the idea of representing the real power meter which is not physically connected to the KNX network of the end user as a sensor device in this network. At this moment, the discussion is referred to the customized station (server) where the data from power meter acquired through LoRa network is stored as the following format.

Table 2. Example of data stored in the customized server

Time (hh.mm)	OBIS	Data	Note (This is explanation and not considered as data for processing)
00.00	1.8.0	100*kWh	1.8.0 is referred to total imported active power or total consumption.
00.10	1.8.0	120*kWh	
00.20	1.8.0	130*kWh	
00.30	1.8.0	130*kWh	
00.40	1.8.0	140*kWh	
00.50	1.8.0	180*kWh	
01.00	1.8.0	200*kWh	
……	……	……	
23.50	1.8.0	1000*kWh	

The table above represents a sample of recorded values of total imported active power which is stored at the customized server. The similar records are stored for the other quantities such as total exported power, current of phases, voltages of phases and frequency of phases.

The server, when received the requests, will process the data and add them to telegram before sending it back to the client. As we have many quantities stored in customized sever thus there can be multiple requests reads from the client for corresponding data. Therefore, the server and client are implemented in such a way where both of them can understand each other in order to transmit the data correctly.

The solution behind it is to bind the unique device address in the KNX to the unique OBIS code of quantity. In the previous section, the network (bus) topology of KNX is explained, each device in the bus is assigned with a unique address. The figure below is a quick remind about the addressing of device in the KNX network.

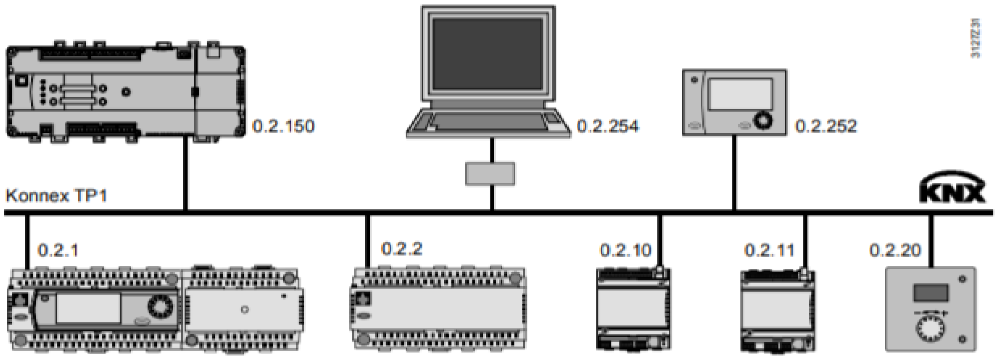


Figure 37. Addressing devices in KNX bus

In the design of server and client, each quantity will be bind to a unique address, therefore, there will be several virtual sensors on the same server and the client will access each sensor through agreed biding table on both devices. The example of a binding table is listed in the table below.

Table 3. Binding table of OBIS code and KNX individual address

Quantity (Considered as a virtual sensor)	OBIS code	Unique device address of KNX
Total imported power	1.8.0	1.1.1
Total exported power	2.8.0	1.1.2
Current phase 1	37.7	1.1.3
Current phase 2	51.7	1.1.4
Current phase 3	71.7	1.1.5
Voltage phase 1	32.7	1.1.6
Voltage phase 2	52.7	1.1.7
Voltage phase 3	72.7	1.1.8
Frequency	14.7	1.1.9

The visualization of each virtual sensor implemented on server and client is shown in the figure below.

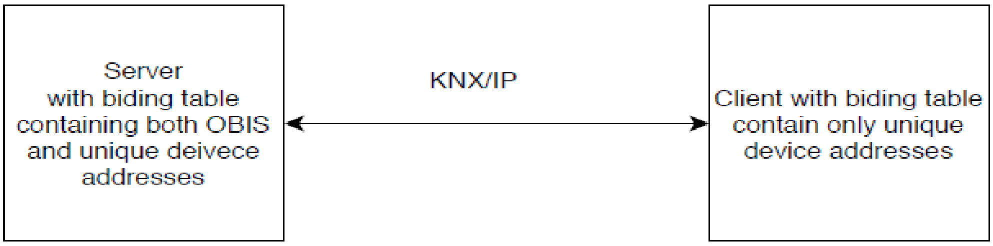


Figure 38. Server-client communication with binding table

As in the previous discussion, the implementation of the server-client model is based on KNX-IP protocol with direct tunneling mode and that means both devices communicate with each other directly using the fixed IP address. Especially, in KNX IP network exists a gateway device where its functionality is forward the data from bus address to IP interface. Generally, the gateway act like a domain converter which can convert from different medial of KNX such as bus to IP and backward.

The KNX/IP works on UDP protocol, therefore it is inherited all the attributes from UDP transport layer which is discussed in section 5.2 (KNX/IP stack), the exchange data between server and client is accomplished by the following sequence.

1. The client sends a CONNECTION REQUEST
2. The server received and sends CONNECTION RESPONSE
3. The client sends a CONNECTIONSTATE_REQUEST
4. The server received and sends a CONNECTIONSTATE_RESPONSE
5. The client sends a TUNNELING_REQUEST asking for data it needs
6. The server sends a TUNNELING_ACK to accept the request
7. The server sends a TUNNELING_REQUEST containing data reception for a client
8. The client sends a TUNNELLING_ACK indicating the data is received
9. The client sends a DISCONNECTION_REQUEST for shut off current data transmission
10. The server received and sends back a DISCONECTION_RESPONSE accepting shut off connection.

    The figure for this process is shown in the next page

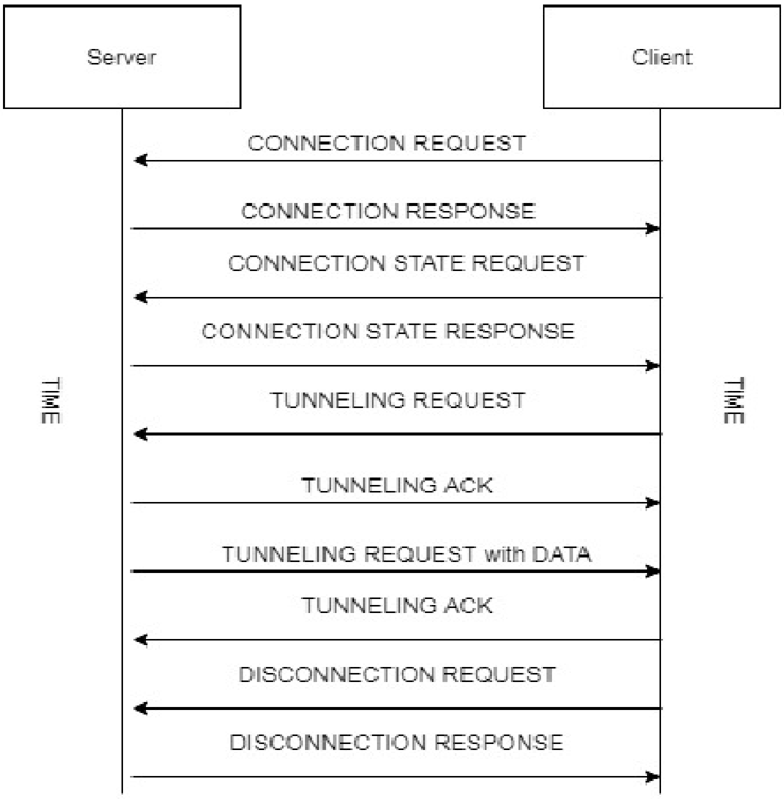


Figure 39. Connection diagram of KNX IP between server and client

Chapter 6

Conclusion

In this thesis, by interfacing the exchange board RT5350F and LoRa modulation module with the power meter, we are able to establish a radio connection for the power meter connected to the LoRaWAN network. The interfacing of the exchange board RT5350F with the power meter is accomplished by the international standard IEC62056-21 mode C with readout mode only through an optical – USB adapter. Thus, it is possible to use the exchange board in the future with others model of power meters which are compliance with this standard with some modification, depending on the manufacturer. The exchange board with implemented scheduler is able to read the data from the power meter, and send the data periodically to the could service of LoRaWAN network using LoRa modulation module. For the LoRa modulation module, the interfacing with the exchange board is conducted through a serial communication with the LoRa chip. The configuration parameters for LoRa modulation module are selected according to EU regulations in order to make the radio transmission compatible with the rules.

At this point, the power meter is considered as a sensor in LoRaWAN network and the collected data is ready for binding with applications. It is need to be noticed that, the data arrived at the cloud service of LoRaWan network is prepared from the exchange board with OBIS code, which is defined in IEC62056 standard. As the aim of the thesis is to corporate the sensor of IoT network to home automation system, thus, the simuation of Home automation system is created. This simulated Home automation system is based on one of the common standard in Home automation industry which is KNX. This simulated KNX home automation system is designed with model of client and server, where the KNX client acts as real user request to specified sensor in the KNX network and KNX server acts as a gateway unit in the KNX network. In detail, the KNX server which comprise of two part, first part responses for receiving data from LoRaWAN cloud services and stored them as desired format. The second part of the KNX server response for converting stored data (IEC62056 standard) to KNX standard. After that, the clients (or users) can access these data under the KNX standard which is compatible with the KNX system that they are using.

Beside that, among several existing wireless solutions such as 3G/4G, GSM, Zigbee, or other protocols, the advantages of using LoRaWAN network for this design is to reduce the complexity of the system as well as the effort of installation for the customer. Thanks to the LoRaWAN protocol characteristic, the data is transferred from power meter to the application server remotely and securely. By defining the data collected from the sensor node (power meter) into the custom format, we can later extract the data on application according to our need.

The combination of a smart power meter with LoRaWAN flatform gives mobility to the smart power meter. It means the installations procedures for Smart power meter is reduced thus reduces the cost as a result. For example, installation of smart power meter does not need to be closed or in a range of existing infrastructures. Using IoT network (LoRaWAN network in this design) as independent flat-form helps to separate the power meter with constrained connections with the existing network. For example, the power meter is not obligated to connect to the central controller of the HAN system or connect to data concentrators/collectors in the bus-based system (DLSM/COSEM, KXN, M-BUS…).

As LoRaWAN flat-form is connected through bridge microcontroller boards, it provides easier upgrade method for existing network because most of the smart power meter support common communication standards (referred to serial and optical ports).
The data acquisition and processing are handled through LoRaWAN system providing a separated data plan for a smart power meter. Therefore, users or utilities, can access the data independently and support cross flat-forms.

From the design, it is important to take in to account the transmission parameters of LoRa physical layer since these parameters will influence the design and application. These parameters decide the power of transmission (link-budget), communication rages, quality of transmission (data rate, time on air), size of the network. In this design, there is only one end device (one power meter) considered, thus the effect of these parameters on the size of the sensor network is not deeply concentrated. However, for the future work and application, the parameter selection will have huge impacts on the designs such as a number of transferred by accepted for each devices (due to on-air time) or qualities of the received signal and also the size of the network (related to the duty cycles).

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APPENDIX

A. EXCHANGE BOARD WITH POWER METERIMPLEMENTATION DETAILS

In this section, the detail implementation of the power meter with the exchange board RT5350F will be discussed.

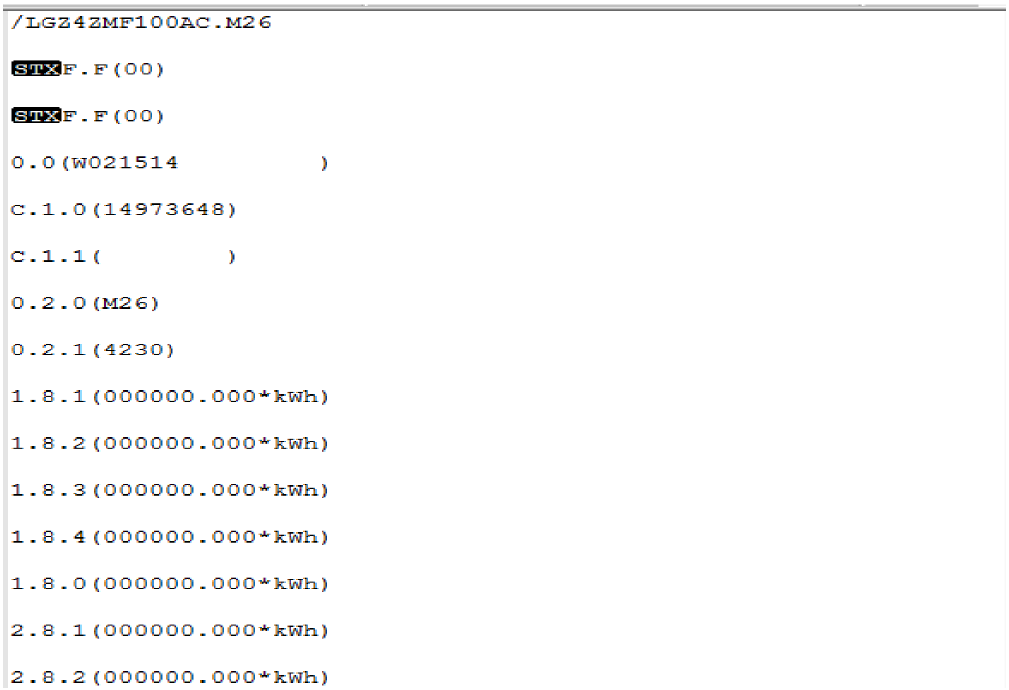
The power meter communicated with the exchange board with the following settings: The RT5350F Exchange board uses the serial USB communication power denoted as ttyUSB0 with the standard of RS232 with the following configuration:

- Baudrate: 300 bits/s
- Data bits: 7 data bits
- Parity: Even Parity
- Stop bit: 1 stop bit
- Flow control: off

For read-out procedures, it is necessary to initialize the communication with the power meter by using the sending 2 commands below before the power meter release its data:

1. RT5350F sends Querry string: “/?!\r\n” (HEX: 0x2f,0x3f,0x21,0x0d,0x0a)
2. Meter responses number of model: /LGZ4ZMF100AC.M26
3. RT5350F sends read-out request command: 0x06,0x30,0x30,0x30,0x0d,0x0a (Hex), This command indicates that we want to read the data from the power meter
4. Meter starts to response with the data.
5. When the readout phase is terminated, the last character from the meter will be “!”

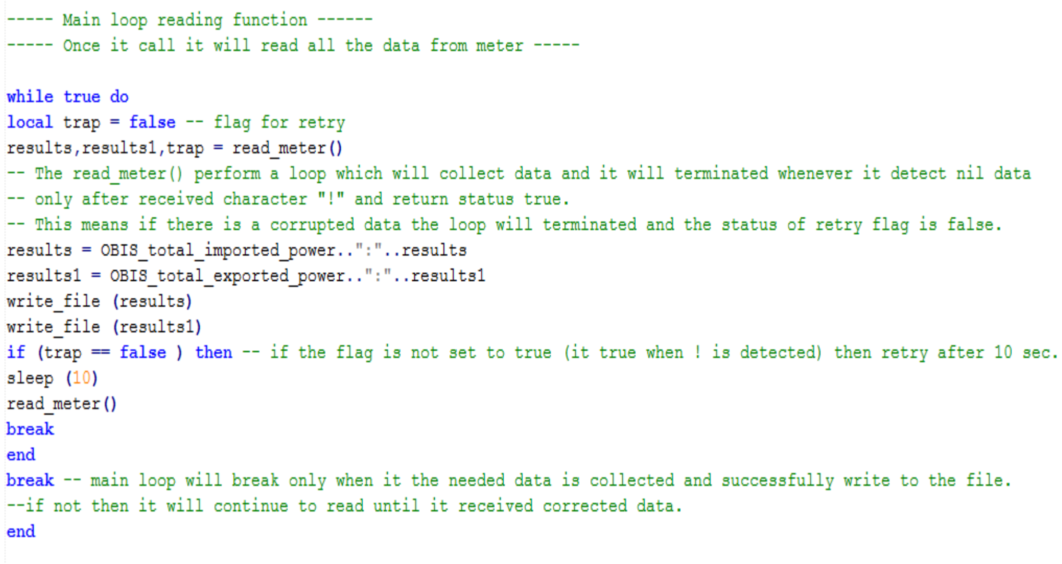
The readout data from the meter can be seen as the following format:



```
/LGZ4ZMF100AC.M26
STXF.F(00)
STXF.F(00)
0.0(W021514         )
C.1.0(14973648)
C.1.1(        )
0.2.0(M26)
0.2.1(4230)
1.8.1(000000.000*kWh)
1.8.2(000000.000*kWh)
1.8.3(000000.000*kWh)
1.8.4(000000.000*kWh)
1.8.0(000000.000*kWh)
2.8.1(000000.000*kWh)
2.8.2(000000.000*kWh)
```

Read-out failure prevention: During the read-out phase, there is a probability of failure which causes the interrupted/missing data from the power meter. This failure happens unpredictably because of many reasons, such as internal interrupt from the power meter, the serial transmission failed (since no follow control), etc… It means

that the RT5350F exchange board would not fully collects data (they will never reach the terminated character “!” from the meter). Therefore, it is necessary to provide a mechanism to prevent this behavior. Particularly, in this work, by experiment on read-out behavior, there is a retry mechanism implemented. If the read-out for the first time is not successfully done, it will retry to read after 10 seconds. With this mechanism, we always can collect data with full cycle (mean that we always catch the character “!” at the end).
The following piece of code will represent the main cycle of read-out which is implemented on RT5350F exchange board.



```
----- Main loop reading function ------
----- Once it call it will read all the data from meter -----

while true do
local trap = false -- flag for retry
results,results1,trap = read_meter()
-- The read_meter() perform a loop which will collect data and it will terminated whenever it detect nil data
-- only after received character "!" and return status true.
-- This means if there is a corrupted data the loop will terminated and the status of retry flag is false.
results = OBIS_total_imported_power..":"..results
results1 = OBIS_total_exported_power..":"..results1
write_file (results)
write_file (results1)
if (trap == false ) then -- if the flag is not set to true (it true when ! is detected) then retry after 10 sec.
sleep (10)
read_meter()
break
end
break -- main loop will break only when it the needed data is collected and successfully write to the file.
--if not then it will continue to read until it received corrected data.
end
```

B. LORAWAN IMPLEMENTATION DETAILS

In this section, the detail implementation of LoRa unit which is connected to exchange board RT5350, and responses for transferring data through LoRaWan communication with the gateway.

The LoRa board is locally connected with exchange board RT5350 through the serial port with RS232 standard denoted as ttyS1 with the following configuration:

- Baudrate: 57600 bits/s
- Data bits: 8 data bits
- Parity: No parity
- Stop bit: 1 stop bit
- Flow control: off

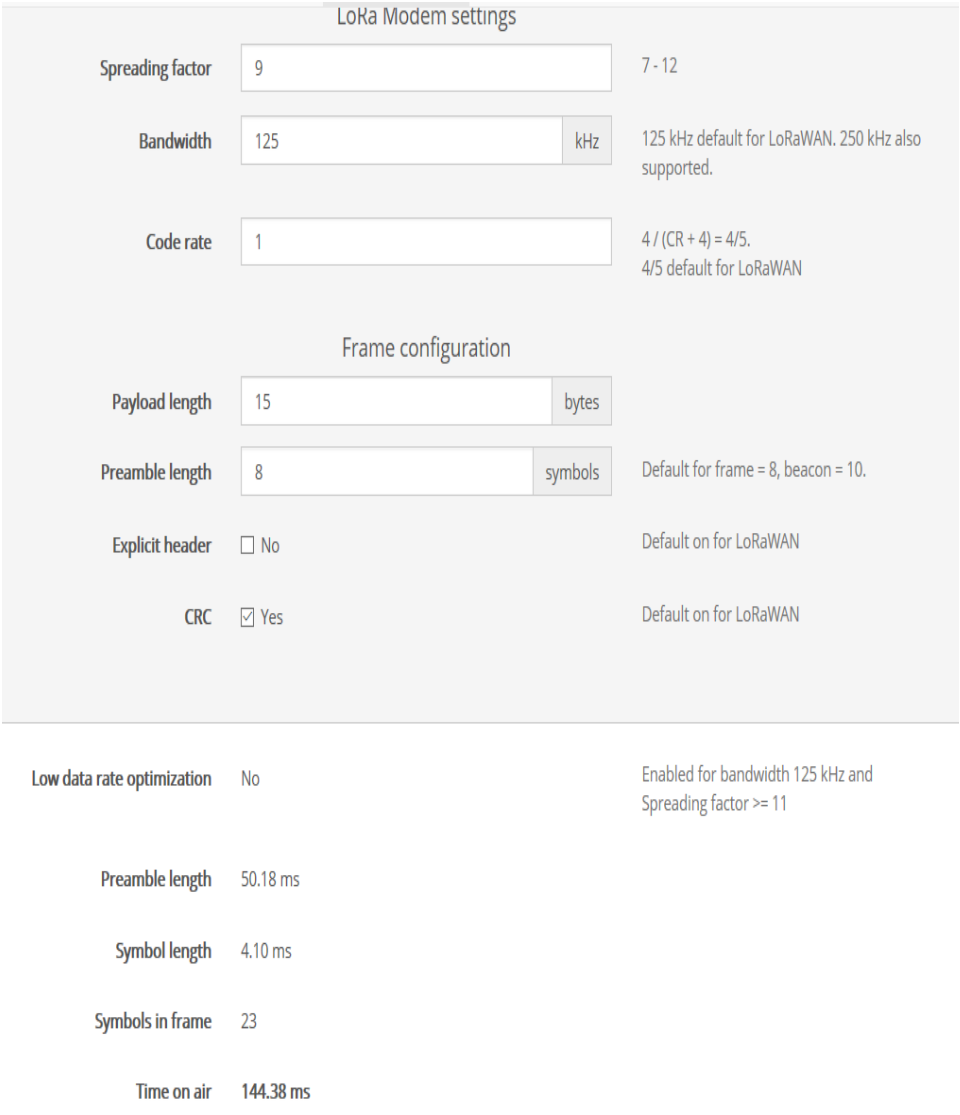
The parameter selection for LoRa on-air transmission is shown as:

- Spreading Factor: 9
- Bandwidth: 125kHz
- Coding Rate: 4/5
- Bit Rate: 5000 bps
- Payload core data: 15 Bytes (figure 27)
- Preamble length: 8 Bytes
- Frequency 869.525 MHz
- LoRa mode: Mode A (no ack after sending data)
- Duty cycle: 1%
- APB activation

- ADR (Adaptive data rate) turned on
- Transmit power: 14dBm
  Calculated on air time for transmisstion based on formular from section 4.2.2 and used two referenece tools:
- LoRa Modem Calcuation tool (program embedded in attached CD)
- Online On air time calculator
  https://www.LoRatools.nl/#/airtime

  The time on air corresponded with selected parameters is:

- Time one Air (ToA): 144.38 ms
- One message can ve send every 14 seconds.



LoRa Modem settings

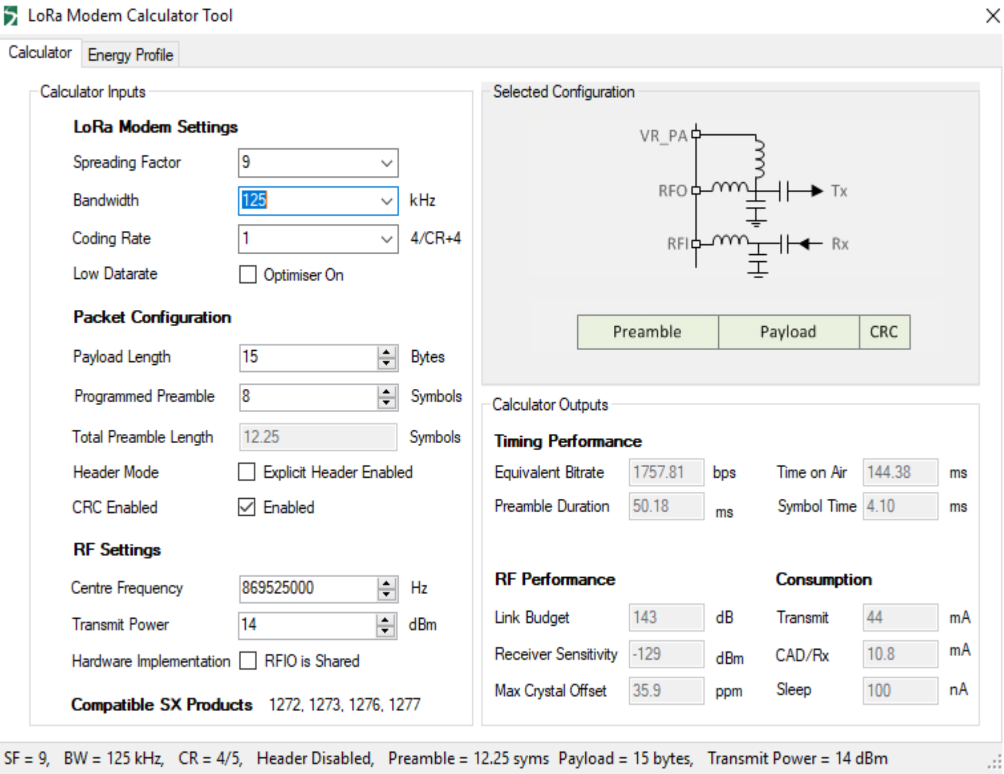
Spreading factor	9	7 - 12
Bandwidth	125 kHz	125 kHz default for LoRaWAN. 250 kHz also supported.
Code rate	1	4 / (CR + 4) = 4/5. 4/5 default for LoRaWAN

Frame configuration

Payload length	15 bytes	
Preamble length	8 symbols	Default for frame = 8, beacon = 10.
Explicit header	☐ No	Default on for LoRaWAN
CRC	☑ Yes	Default on for LoRaWAN

Low data rate optimization	No	Enabled for bandwidth 125 kHz and Spreading factor >= 11
Preamble length	50.18 ms	
Symbol length	4.10 ms	
Symbols in frame	23	
Time on air	**144.38 ms**	

Figure 40. LoRa Online Calculator



LoRa Modem Calculator Tool

Calculator | Energy Profile

Calculator Inputs

LoRa Modem Settings

Spreading Factor: 9
Bandwidth: 125 kHz
Coding Rate: 1 4/CR+4
Low Datarate: ☐ Optimiser On

Packet Configuration

Payload Length: 15 Bytes
Programmed Preamble: 8 Symbols
Total Preamble Length: 12.25 Symbols
Header Mode: ☐ Explicit Header Enabled
CRC Enabled: ☑ Enabled

RF Settings

Centre Frequency: 869525000 Hz
Transmit Power: 14 dBm
Hardware Implementation: ☐ RFIO is Shared

Compatible SX Products 1272, 1273, 1276, 1277

Selected Configuration

Calculator Outputs

Timing Performance

Equivalent Bitrate: 1757.81 bps
Time on Air: 144.38 ms
Preamble Duration: 50.18 ms
Symbol Time: 4.10 ms

RF Performance

Link Budget: 143 dB
Receiver Sensitivity: -129 dBm
Max Crystal Offset: 35.9 ppm

Consumption

Transmit: 44 mA
CAD/Rx: 10.8 mA
Sleep: 100 nA

SF = 9, BW = 125 kHz, CR = 4/5, Header Disabled, Preamble = 12.25 syms Payload = 15 bytes, Transmit Power = 14 dBm

Figure 41. LoRa Software calculator

C. SERVERS IMPLEMENTATION DETAILS

Applications server contains two part which are implemented on the same virtual machine (Linux Cent OS):

- Network Server for receiving data from LoRaWan, in detail the cloud service(3rd party API) and pushes the data to this server. Main responsibility of this server is to received data from LoRaWan and prepare it to the application server
- Application server response for collect prepared data from network server and interfacing the data with the HAN network by using the same protocol. In this case is KNX/IP protocol

ATTACHMENT FOLDERS AND FILES SCHEMATIC OF PROJECTS ON CD