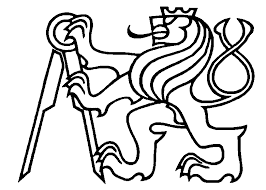
***CZECH TECHNICAL UNIVERSITY IN PRAGUE***

***FACULTY OF ELECTRICAL ENGINEERING***



**MASTER THESIS**

**Cooperation of Home Automatization Systems with Sensors in IoT network**

**Author:**

**Phuc Trinh Gia**

**Supervisor:**

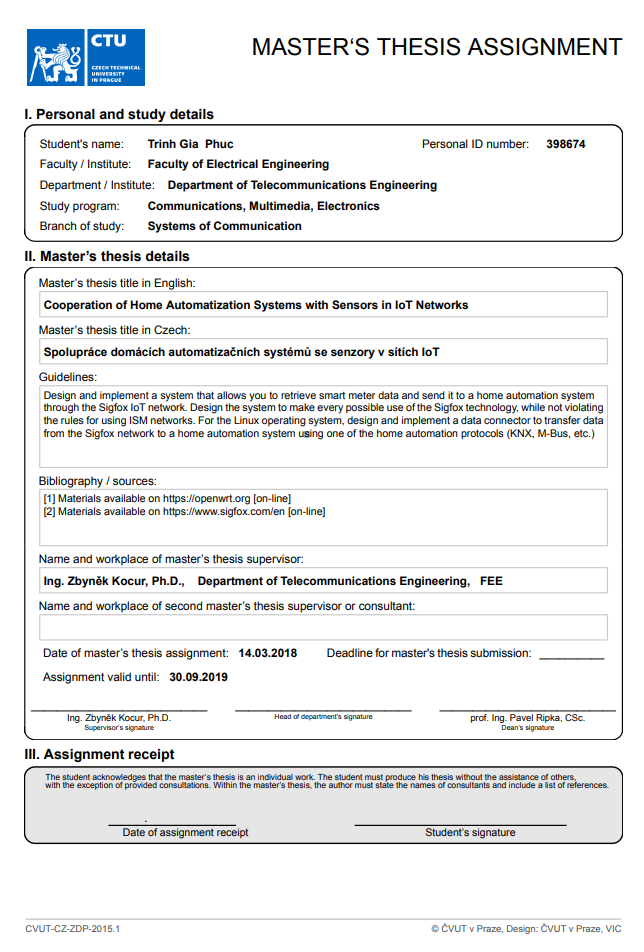
**Ing. Zbyněk Kocur, Ph.D**

**Reviewer:**

**PRAGUE**

**2019**





**Abstract**

Nowadays, Internet of Things (IoT) are developing rapidly and vastly and goes along with its development are the technologies behind which create the eco-system based on Internet back-bone 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 back-bone 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 smart power meter and send collected data through IoT network using common current technology such as Lora or Sigfox 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.

**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 advices.

I am also grateful to ….., for his review, comments, and evaluation for my thesis which gives plenty of experiences for my works.

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**

**………………………………………….**

**Prague, 2019**

Contents

[Introduction 8](#_Toc2611976)

[1.1 Purpose and structure of the thesis 8](#_Toc2611977)

[1.2 Hardware and software overview 9](#_Toc2611978)

[Analysis of Networks and Technologies 11](#_Toc2611979)

[2.1 Overview of smart power meter 11](#_Toc2611980)

[2.2 Home automation network 13](#_Toc2611981)

[2.3 Internet of Things 14](#_Toc2611982)

[2.4 Analysis the usages of power meter in Home Automation Network 16](#_Toc2611983)

[**a.** **Case 1: Smart power meter is directly connected to HAN controller** 16](#_Toc2611984)

[**b.** **Case 2: Smart power meter is connected to HAN but has itself data flow path for server/cloud services [15]** 17](#_Toc2611985)

[**c.** **Case 3: Smart power meter is connected to AMI by some industrial protocols using for buiding management.** 18](#_Toc2611986)

[Motivation and design 21](#_Toc2611987)

[3.1. Problems and motivations 21](#_Toc2611988)

[3.2. Proposed solution and design 23](#_Toc2611989)

[LoRa technology and application 25](#_Toc2611990)

[4.1. Introduction to LoRa technology 25](#_Toc2611991)

[4.2. Interfacing of power meter with RT5350 28](#_Toc2611992)

[4.3. Interfacing LoRa module with RT5350 30](#_Toc2611993)

[KNX and application 33](#_Toc2611994)

[5.1. Introduction to KNX 33](#_Toc2611995)

[5.2. KNX-IP stack 35](#_Toc2611996)

[5.3. Interface KNX server for HAN application 36](#_Toc2611997)

[Conclusion 41](#_Toc2611998)

[Bibliography 41](#_Toc2611999)

**List of Figures**

**Chapter 1**

# Introduction

## 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 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 couple of fields and technologies are included such as LoRa network, KNX home automation standards and KNX IP protocol.

**Chapter 1 – Introduction.** This chapter is an introduction of materials and tools which used forbuilding the project on 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 in 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. These analysis help to figure out the problems existing in current infrastructures and create a basement for the next chapter in 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 homautomation network with real life demands. The study inclued the motivation to solve the current problem of monitoring power consumption for some critical properties in the Czech repubic and following by the proposed solution. The proposed solution comes together with sugested design for solving the problem in which the LoRa technology is invoked to deal with current obstacles.

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

**Chapter 6 – Conclusion.** The final discussion about project with proposed solution and design.

## Hardware and software overview

In order to retrieving 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 optical-serial converter. On the other side, the board connects with Lora module through serial port. 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 with optical port used for measuring power consumption and other electrical quantities such as electric-current, voltage, frequency, power factors,etc.
* Olinuxino – RT5350F is used as exchange board for collecting data from 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 Lora Gateway.

Descriptions:

* 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, 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 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 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 power meter and LoRa module.



Figure 2. Olinuxino RT5350 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 following component:

* OpwenWrt
* Lua Scripting
* Python
* Centos for server

**Chapter 2**

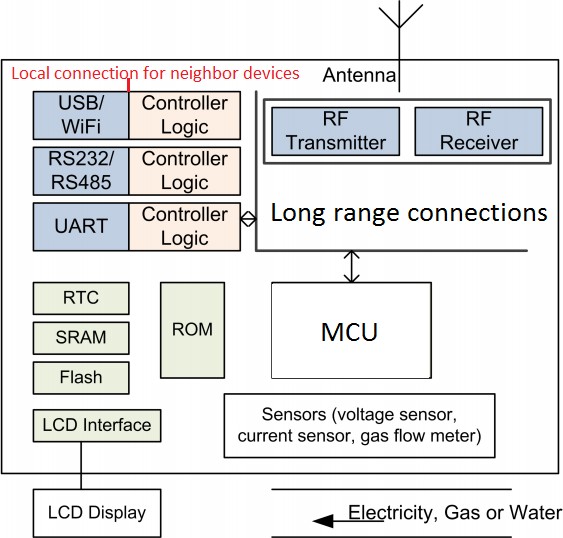
# Analysis of Networks and Technologies

## Overview of smart power meter

The smart power meter is the next generation of an analog power meter, it 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 measures 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. [14]

* + No more estimate bills: The accuracy of digitalized measurement in smart power meter helps to get rid of estimated bills when a meter reader is unable to access the property. Means that the company does not have to come to their customer location for collecting the data.
  + Detail usage of electricity: With an analog meter, most power bill shows to customers how much electricity they used for last month (or several months) – but not how they used them. A smart meter records customer’s electricity usage for every hour give access to their usage quickly and even shows them what is the device is using the most electricity power in there house.
  + User friendly: With a smart power meter, customers can monitor the power consumption and choose proper appliances with different behavior and make an effective decision.
  + Consulting: Power companies can consult their customers with proper tariffs with the different process at different times or days according to the customer’s needs.
  + Improve the environment: Use less energy means reducing pollutions to the environment.
  + Safety enhanced: Smart power meter can detect failure problems that are happened in electrical network and can either automatically decided situations ( set an alarm/ controlling automatically switching system) or sending a report to users/companies.

In this section, a 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.



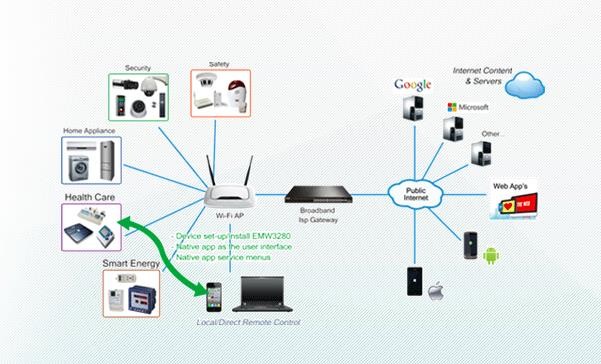
**Figure 4. Hardware demonstration of smart power meter [4]**

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.

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 power meter is the one with local communications such as Ethernet , RS485 KNX,DLSM/COSEM.

## 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 for and connected to the Internet so users can monitoring, scheduling, controlling those devices according to their need remotely. 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 base 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. Topology of HAN network [1]**

From the 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 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 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 the communication protocols. For example, the internal devices (sensors, actuators) are connected with central controller by wireless communication protocols (Zigbee, Z-wave, Bluetooth, Wifi, etc) with the maximum distance is 10- 300m (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 is a problem because the distance 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 asynchronization for the system. For example, if users want to add extra internal devices (sensors or actuators) they need to select the devices with same protocols or some time from the same manufacturer. Furthermore, the application services are also provided differently by each manufacturer.

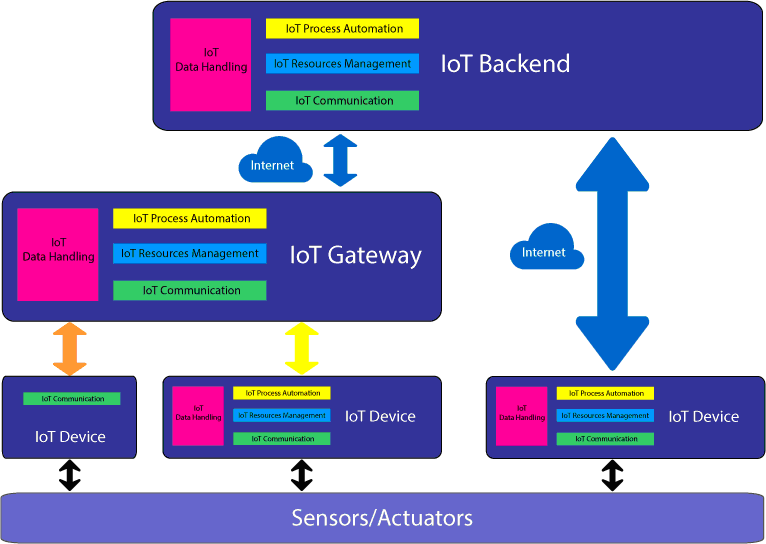
## Internet of Things

Internet of thing (IoT) is a network where all devices in the network are interconnected and communicate to 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 the aspects of life. From the perspective of how IoT devices are interconnected and operate the Internet Architecture Board classified them into following class: [17]

* + - 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

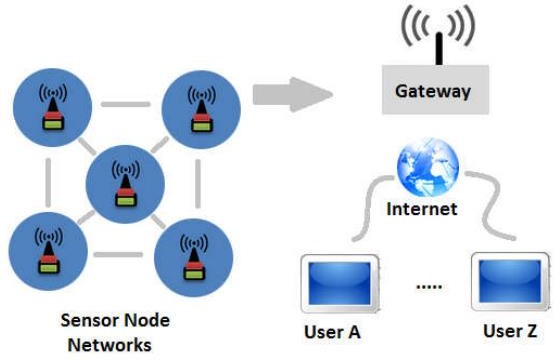
Cloud. In this model, the application gateway is always considered as an intermediate server between IoT devices and clouds.

* + - 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. Topology of IoT network [2]**

One of the most important element 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 IoT network. [11]



**Figure 7. Topology of WSN in IoT network [3]**

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

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

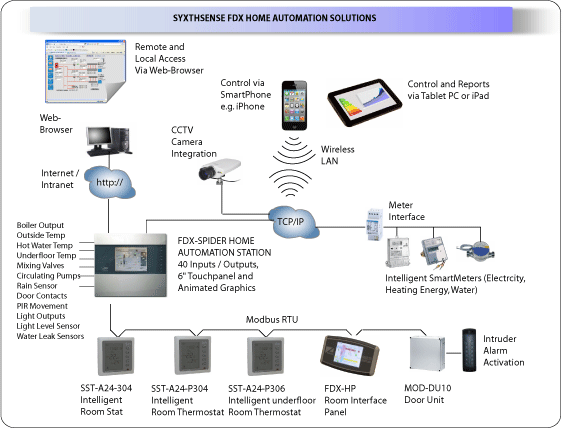
* + - * The IoT network itself uses specific radio technologies providing ultralow power consumption which mean that the sensors can run with battery sized power supplies and lasts for years.
      * The radio technology which is designed for IoT network with long range communication with low data rate. In general, technologies such as LoRa,Sigfox, or NB-IoT provide the connection distance from sensors to gateways with range from 2-10Km depends on 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).

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

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

### **Case 1: Smart power meter is directly connected to 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 figure below



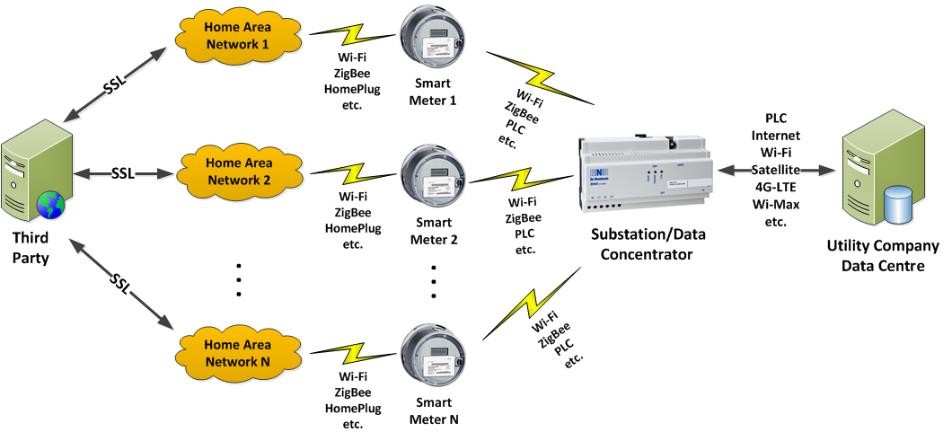
**Figure 8. Smart power meter connected to central controller [5]**

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 central controller of HAN.
* This method also limits the ability to create a connection to neighbor network area (NAN). There is no possibility for interfacing with IoT network.
* The power meter needs to be preprogrammed in order to communicate with the central controller. As mentioned before, each manufacture has different protocols thus the compatibility of the smart power meter is limited.
* The smart power meter is must be installed within communication range of HAN controller.

### **Case 2: Smart power meter is connected to HAN but has itself data flow path for server/cloud services [15]**

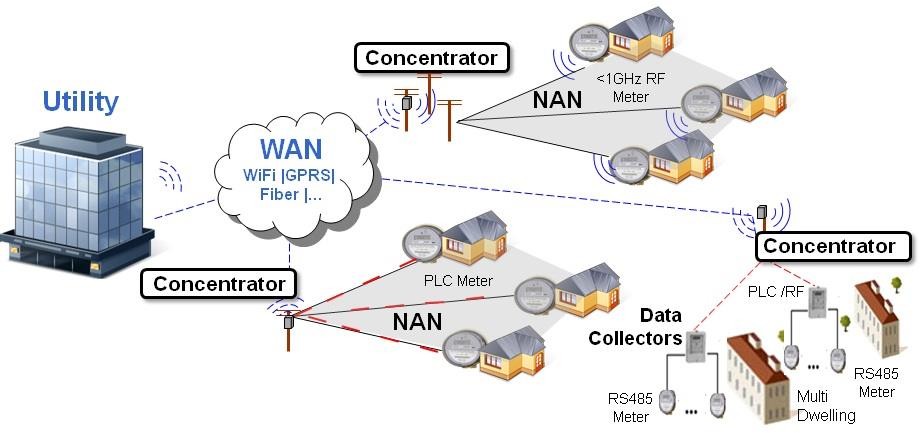
This method gives better options for the smart power meter to communicate with HAN as well as among themselves by wire or wireless media. The figure below demonstrates the case when smart power meters are connected.



**Figure 9. Smart power meter connected to Data concentrators [6]**

In this configuration, smart power meters have themselves data paths and separate data plan from stream data of 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 [7]**

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

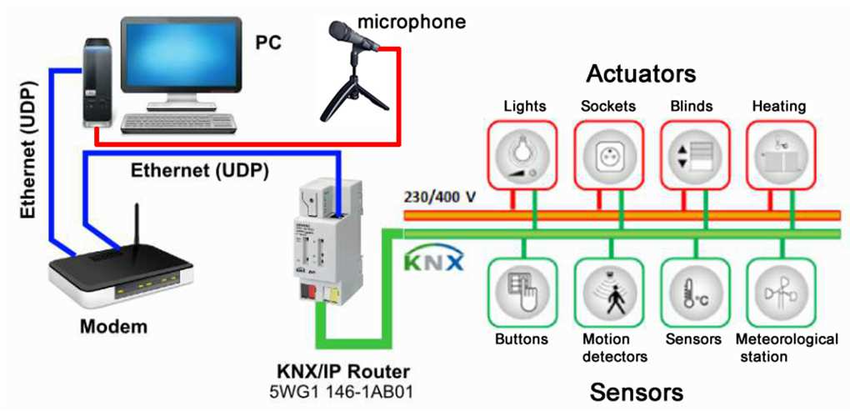
However, there are still several disadvantages to this method.

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

### **Case 3: Smart power meter is connected to AMI by some industrial protocols using for buiding management.**

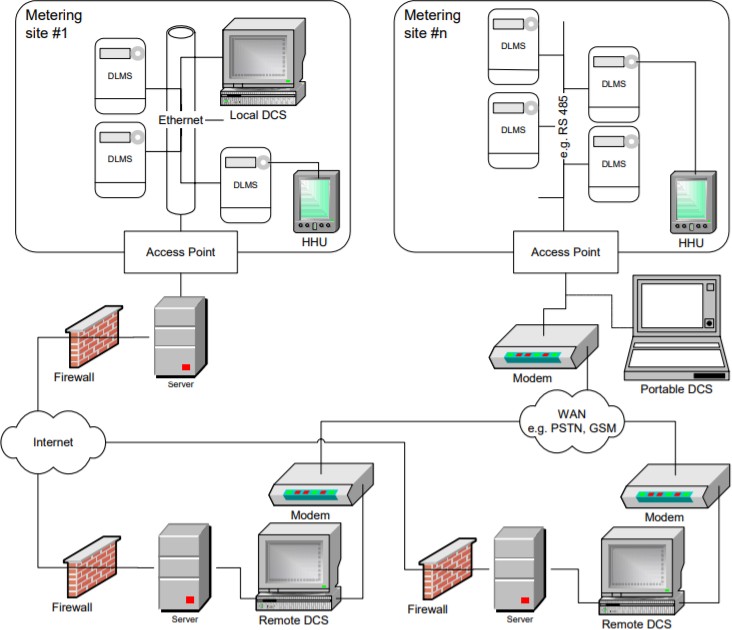
This study case is inherited from previous study case (Case 2) but it specified by communication protocols for wire media connection.

Protocols such ask DLSM/COSEM, KNX, MODBUS, M-BUS (Meter -BUS), etc are frequenly 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** [8]

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 manufactures in 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 extra cost for installation.
* These protocols are good for monitoring building and middle side areas but it can cause low effiency problem to the bigger network (NAN) because of 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 buiding where the smart power installed running on DLSM/COSEM the collected data is encapsulated and sent in a different way and in other buiding where power meters running on M-BUS causing the different way of data reception. Therefore, it is hard for the utility to synchronized these data.

From case studies, there are some disadvantages from exiting 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

## Problems and motivations

In chapter 2, the overview on 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 existing system in electrical power measurement/monitoring. Base on studied problems, the proposal design is come up with solutions for solving the problem and satisfy the demands.

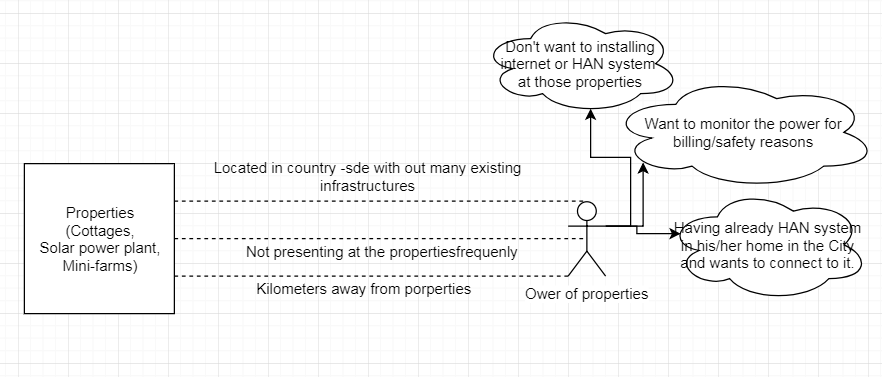
Nowadays, in the Czech Republic, the demands on private cottages or private power solar plants or farms are increased rapidly. First of all, these properties are usually located not in urban area, people are using cottages for weekend relaxing, solar power plant for harvesting electricity from the Sun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

* + - For monitoring power consumption in these properties, the “cheapest” solution of 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 of existing infrastructure for Internet or other AMI system such as DLSM/COSEM or KNX which are using for power monitoring.
    - The Internet connection for these properties are 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 significant amount of money and wasting fees for montly payment since people/owners are not always presents there.
    - Obviously, the installation of Home automation system is not necessary since the demands for it is really low and of course on 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 easy and economical solution for deploy such kind of technologies such as Internet or HAN in these areas.

Let’s come back to the facts that the requirement for monitoring/reporting power consumption are on high demands for these property and owners/users need a quick, simple, economical saving solution for this. Of course base 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 installing such an expensive equipment (such a power meter with 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?
* Of course we can use other technology in AIM system such as DLSM/COSEM or KNX infrastructures but these properties are located not in 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 problem above is to find the affordable solution which is cheap, simple, easy to install and reliable for monitoring of power consumption.

## 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 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

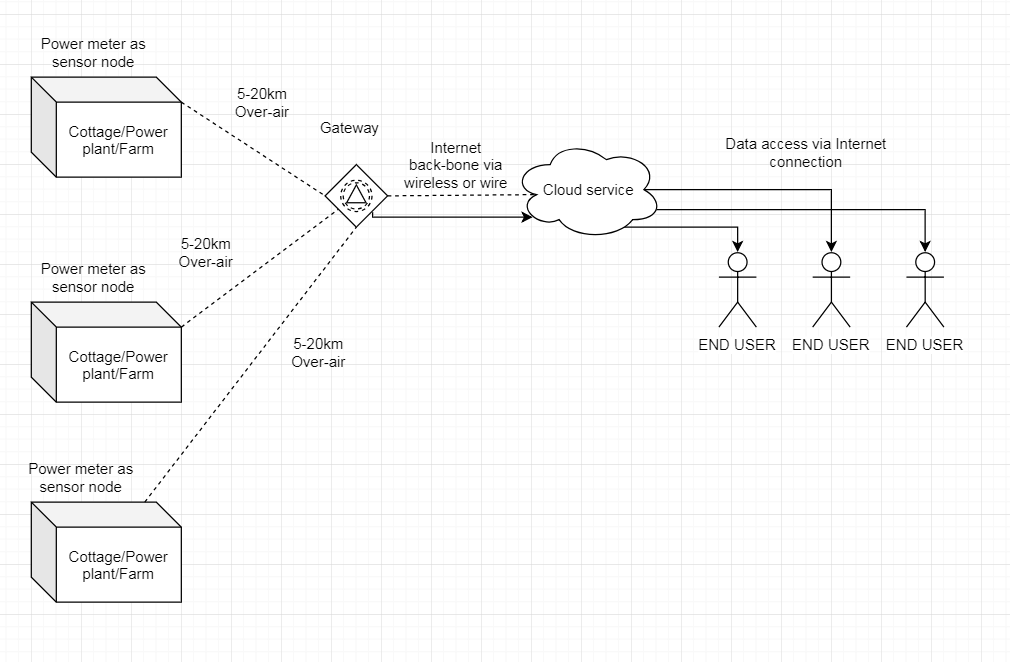
Those methods above are required a lot of efforts and costs for installation/operation thus the proposed solution is to upgrade the power meter become a sensor in IoT network and the data collected from power meter will be sent to the IoT gateway and then forward to the Internet. This proposed method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

* + - 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 power meter and send them to the IoT gateway. Thus the effort for installation is saved.
    - The data can be collect and sent periodically by 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 LoRa technologies 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 designs on system point of view such as:

* Each power meter can be considered as a sensor node in the network with unique ID, thus scale of the network is expandable without limitation.
* Each sensors can be manage by individually or grouped according to user.

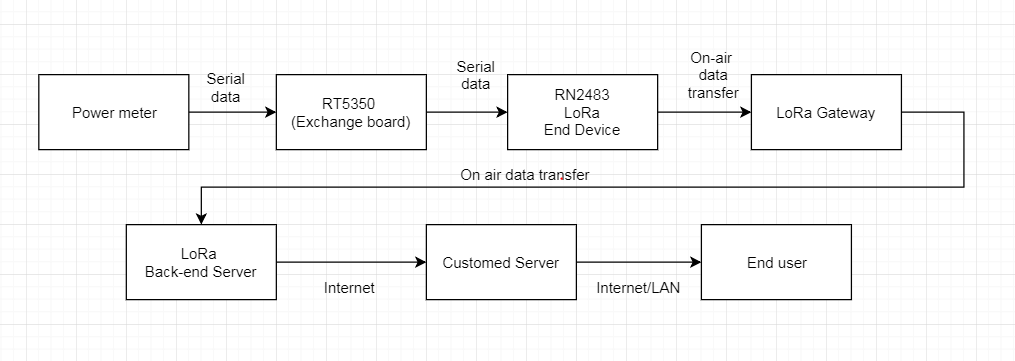
On the system point of view, the data stream from power meter to end user will be demonstrated in following figure.



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

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

In detail, the proposed designs is invoked with following components, the detail implementation of the design will be discussed in 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 a LoRa end device by using an exchange board with the scheduler for periodically send data to the gateway. Then from the gateway these data are transferred to the cloud services through 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**

# LoRa technology and application

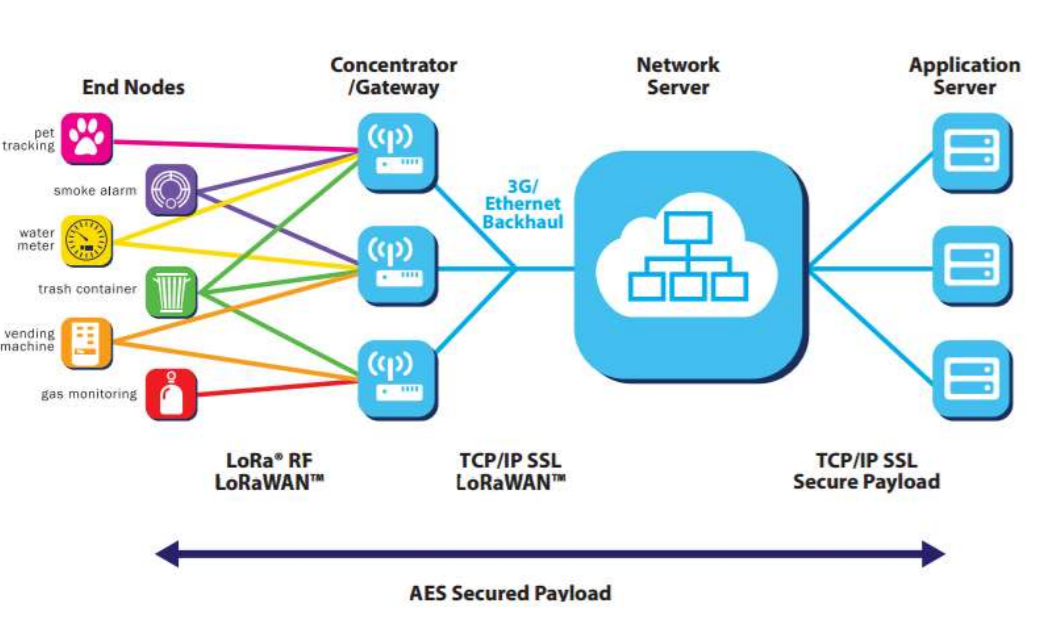
## Introduction to LoRa technology

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

“Gateways connected to the network server via standard IP connections relay messages between end-devices using single-hop wireless communication and a central network server in the backend. The end-point communication supports bi-directional communication as well as multicast enabling software, upgrades over the air, and other mass distribution messages.

LoRa spreads communication between end-devices and gateways across multiple frequency channels and data rates. The spread spectrum technology uses data rates ranging from 0.3 kbps to 50 kbps to prevent communications from interfering with each other, and creates a set of "virtual" channels that increase the capacity of the gateway. To maximize both the battery life of the end-devices and the overall network capacity, the LoRa network server manages the data rate and RF output for each end-device individually through an adaptive data rate (ADR) scheme. LoRa also addresses the need for security by providing encryption at the network level, application level, and device level through the use of a unique network key (EUI64), a unique application key (EUI64), and a device-specific key (EUI128).”

[https://www.semiconductorstore.com/blog/2015/An-Introduction-to-LoRa-Technology/1330/]



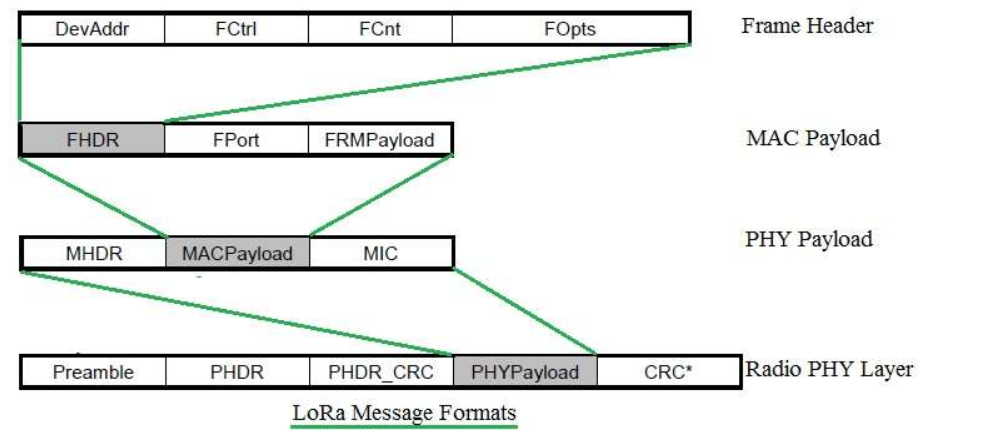
**Figure 16. Overview architecture of IoT network**

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

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

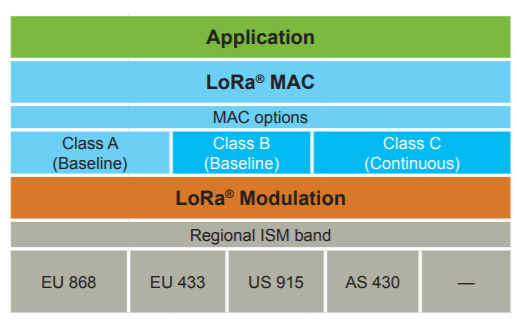
Following are the functions of **LoRa Physical Layer** (PHY):

* Physical Layer constructs the frame in order to transmit payload from MAC layer over 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.



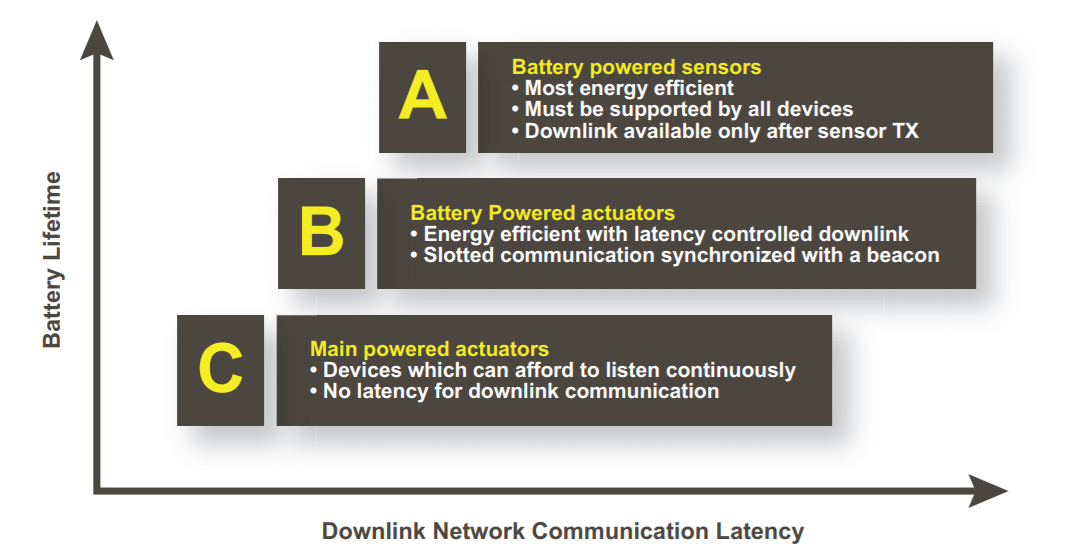
**Figure 17. LoRa message formats**[http://www.rfwireless-world.com/Tutorials/LoRa-protocol-stack.html]

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



**Figure 18. OSI representation of LoRa**

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



**Figure 19. Operation class of Lora and their characteristics**

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

**ED Activation:**

* 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).
* Application session key (AppSKey): Encryption key between ED and Application Server (data)

**Over-The-Air-Activation (OTAA):**

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 ED prior to OTAA:

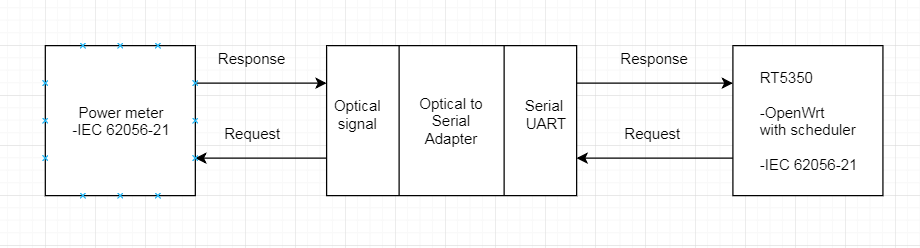
* JoinEUI: global application ID in IEEE EUI64 address space that uniquely identifies the Join Server that is able to assist in the processing of the Join procedure and the session keys derivation.
* DevEUI: Globally unique device identifier in IEEE EUI64 address space.
* AppKey: root AES-128 encryption 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.

[https://fenix.tecnico.ulisboa.pt/downloadFile/1689468335603030/LoRaWAN%20Introduction.pdf]

## Interfacing of power meter with RT5350

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

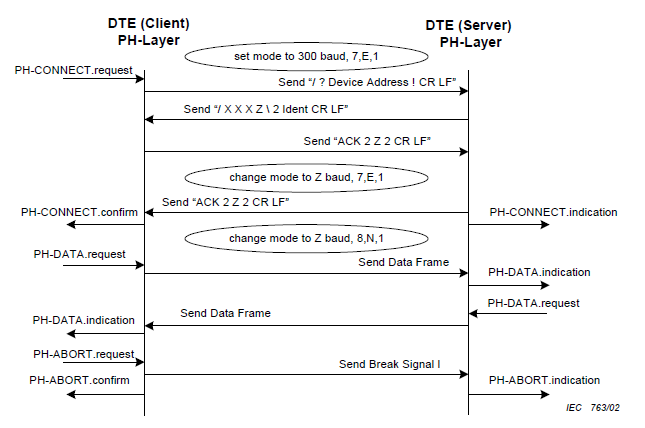
* The power meter with optical port running on IEC 62056-21 Communications Protocol thus the serial data transferred from power meter need to have received according to the protocol.
* The IEC 62056-21 protocol using OBIS codes for indicating the quantities and corresponding values, therefore the data recorded into exchange board should be prepared with full information for applications later.
* The reading of power meter need to be scheduled (by minutes, hours or days)
  + - * These requirements will be explained in detail in next sections, on the other hand the general structure of communication line between power meter and exchange board is shown in figure below:



**Figure 20. Interfacing of 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. “The IEC 62056 standards are the International Standard versions of the DLMS/COSEM specification. **DLMS** or Device Language Message Specification (originally Distribution Line Message Specification), is the suite of standards developed and maintained by the DLMS User Association and has been adopted by the IEC TC13 WG14 into the **IEC 62056** series of standards. The DLMS User Association maintains a D Type liaison with IEC TC13 WG14 responsible for international standards for meter data exchange and establishing the IEC 62056 series. In this role, the DLMS UA provides maintenance, registration and compliance certification services for IEC 62056 DLMS/COSEM.” [https://en.wikipedia.org/wiki/IEC\_62056]

Example of read out phase for power meter according to IEC-62065-21 is show in figure below.



**Figure 21. Network communication diagram of IEC-62065-21 standard**

The data read out from power meter are formatted by using 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:

**A-B:C.D.E\*F**

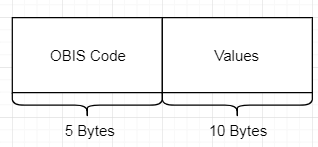
* + The A group specifies the medium (0=abstract objects, 1=electricity, 6=heat, 7=gas, 8=water ...)
  + The B group specifies the channel. Each device with multiple channels generating measurement results, can separate the results into the channels.
  + The C group specifies the physical value (current, voltage, energy, level, temperature, ...)
  + The D group specifies the quantity computation result of specific algorythm
  + 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”, therefore the scheduled read for reading out data from power meter are performed by following table.

|  |  |  |  |
| --- | --- | --- | --- |
| Quantity | OBIS | Value | 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 1. Scheduled read out of data and quantities**

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

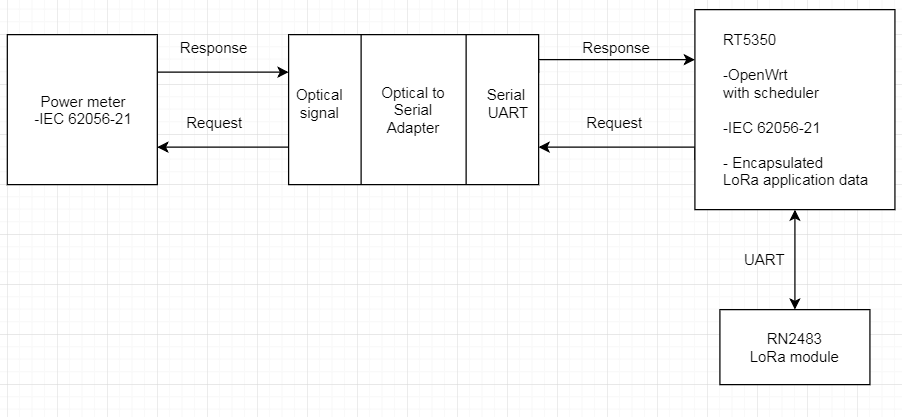


**Figure 22. Format of data read from power meter**

These packed data will be used as the data for application layer in 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.

## Interfacing LoRa module with RT5350

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 gateway. In order to do it, the connection between exchange board and LoRa module is established using serial communication UART, the connection is shown in figure below.

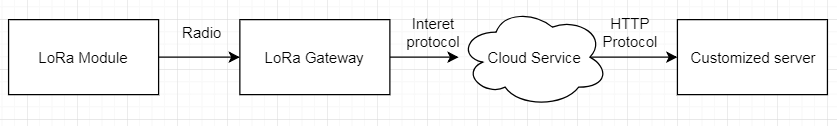


**Figure 23.Interfacing of LoRa module with exchange boar RT5350 and power meter**

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

* Frequency: 868 MHz (EU band)
* Join method: ABP join with private API key and Network key.

At this stage the data or value measured from 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 figure below.

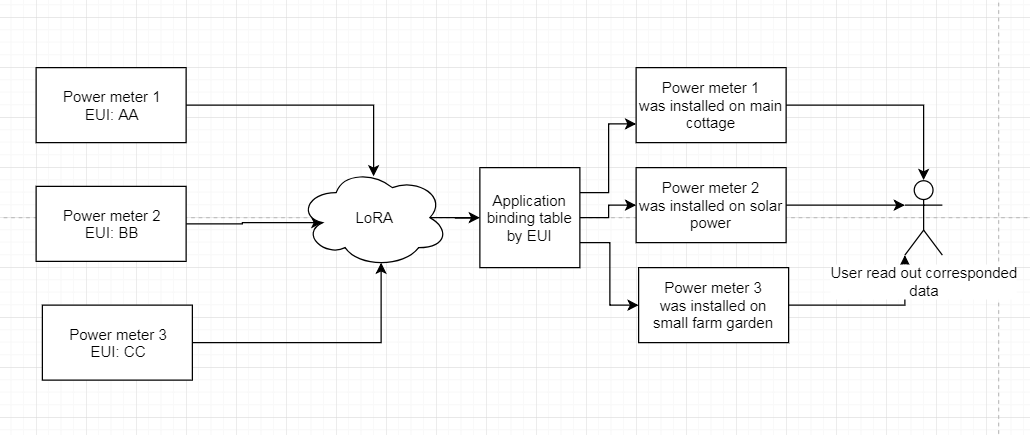


**Figure 24. Data flow in system as a sensor in IoT network**

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 proper way for next application which is KNX and will be presented in 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 index part of this thesis. From the data, some important information are 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 specific identifier of applications. For example, if there are several power meter 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 property (sensor network) will be identified by their UID. The demonstration of the user case can be seen as following figure.



**Figure 25. 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 apply to implement several device in the KNX network and it not only used for power meter.

**Chapter 5**

# KNX and application

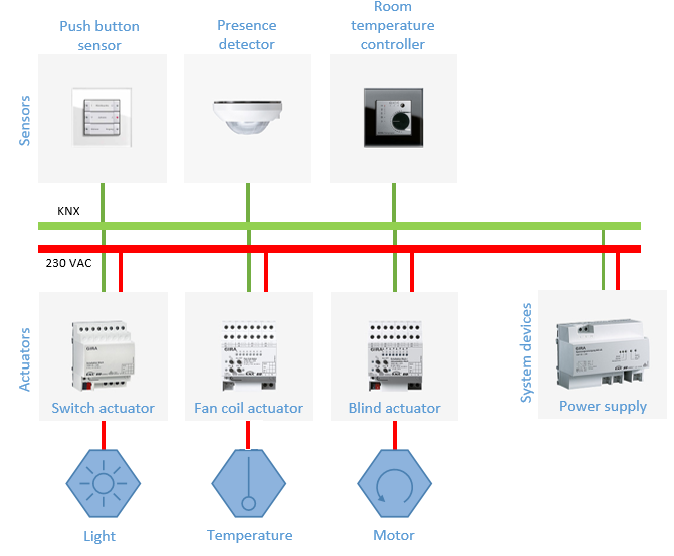
* 1. Introduction to KNX

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. [

Merz, Hermann, Hansemann, Thomas and Hübne, Christof. Building automation : communication systems with EIB/KNX, LON und BACnet. 2009.

]

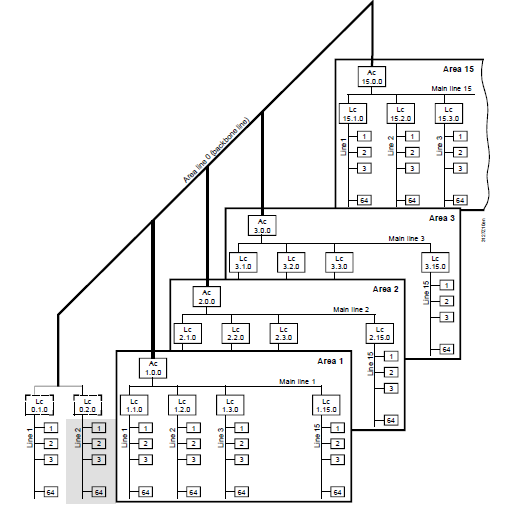
The KNX is technology for home automation using bus topology to construct the network, each device on the bus is able to communicate with each other independently without a central control system. The communication is established by using telegram transmitted on the bus. The mechanism for devices in the bus is considered as ‘listen 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 show in following figure:



**Figure 26. 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:

* 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 27. Full-scale of KNX network architecture**

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 next sections. The frame is later considered the application layer in KNX server client model and its structure is shown in figure below.



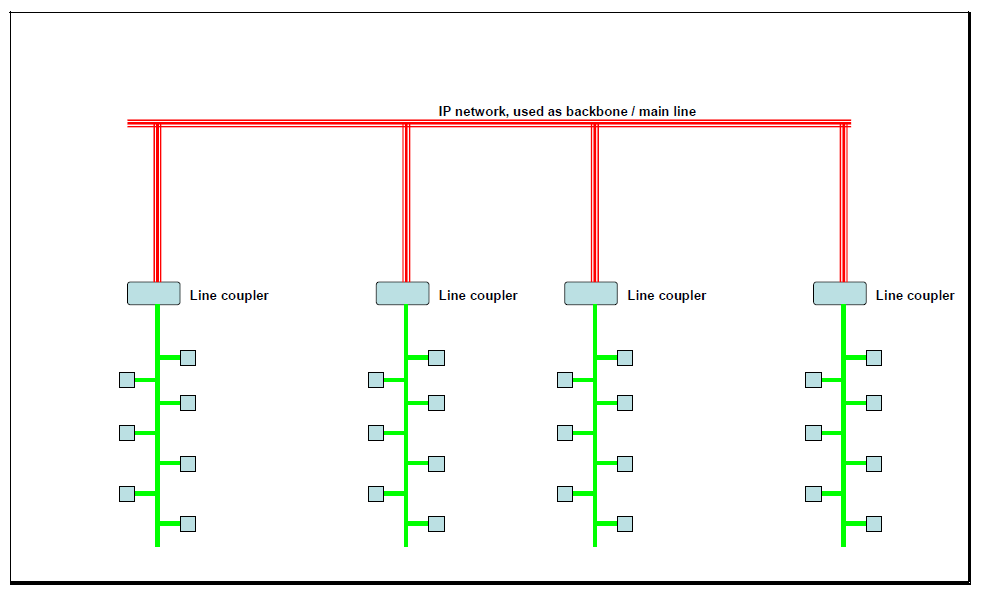
**Figure 28. KNX data telegram**

* ***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.

## KNX-IP stack

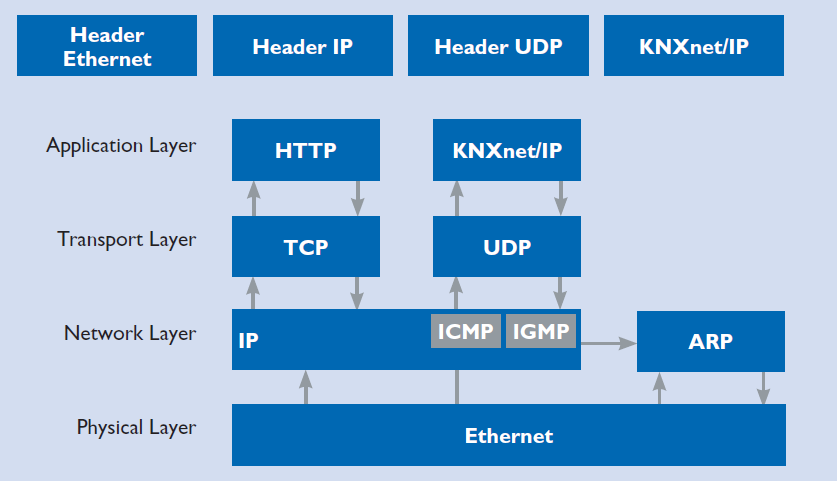
Various communication media and transmission methods can be used in the KNX system, either KNX Twisted Pair (KNX TP), KNX Powerline (KNX PL) uses the existing 230 V mains network, KNX Radio Frequency (KNX RF) communication via radio signal or KNX IP – communication via Ethernet/Wifi. In this section the detail explanation of KNX IP is shown as demonstration for 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 KNX system is by replacing the line couple with KNXnet/IP router which can be seen as in figure below.



**Figure 29. Demonstration of KNX IP network**

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



**Figure 30. OSI model representation of KNX IP**

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

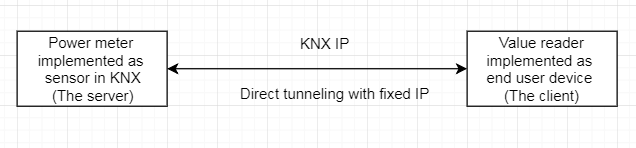
Tunneling is used when two devices want to communicates direct to each other because the physical IP address is assigned to each device and the implementation on software side is done in such a way that it will send only the packets to specific IP address.

Routing is used for simultaneous, connectionless transmission of a KXN device to several other KNX devices. This is equivalent as 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.

## Interface KNX server for HAN application

The section describes the interfacing of data prepared on customized server to the KNX network. The aim of this implementation is to demonstrate the solution for end user in home automation network who is considered as 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, for clarify the working model of the power meter in 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 it measured. On the other side, the end user device (ex: 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 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 indicates the implementation of power meter simulated as sensor device in KNX where data collected from real power meter is prepared in such a way that it can answer any request from client device. The client device is implemented as a value reader for sensors in KNX network where it generates the requests to server and receives corresponded values. Before going in to detail explanation of server and client, the overview structure of their model is shown in figure below.



**Figure 31. Client-server model of KNX implementation**

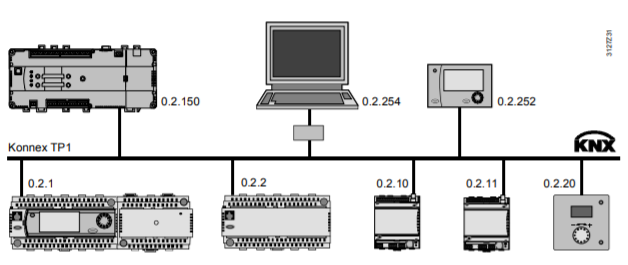
As described above, the server is the idea of represent the real power meter which is not physically connected to the KNX network of end user as a sensor device in this network. At this moment, the discussion is referred to the customized station (server) where the data from power meter acquired through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

|  |  |  |  |
| --- | --- | --- | --- |
| 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. |
| 00.05 | 1.8.0 | 110\*kWh |
| 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 |

**Table 2. Example of data stored in customized server**

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



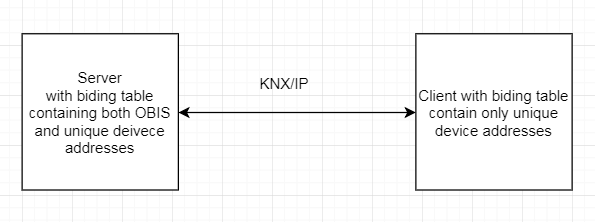
**Figure 32. Addressing devices in KNX bus**

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

|  |  |  |
| --- | --- | --- |
| 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 |

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

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

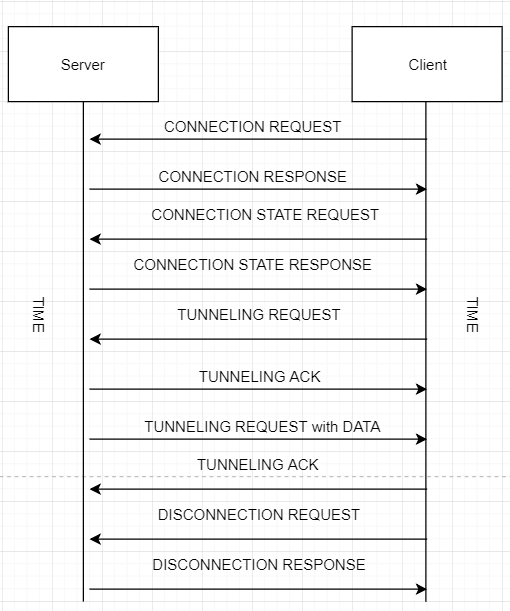


**Figure 33. Server – client communication with binding table**

As in previous discussion the implementation of sever-client model is based on KNX-IP protocol with direct tunneling mode and that means both devices communicate with each other directly using fixed IP address. Especially, in KNX IP network, it is exist a gateway device where it 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 UPD protocol, therefore it is inherited all the attributes from UPD transport layer which is discussed in section 5.2 (KNX/IP stack), the exchange data between server and client is accomplished by following sequence.

* Client sends a CONNECTION REQUEST
* Server received and sends CONNECTION RESPONSE
* Client sends a CONNECTIONSTATE\_REQUEST
* Server received and sends a CONNECTIONSTATE\_RESPONSE
* Client sends a TUNNELING\_REQUEST asking for data it needs
* Server sends a TUNNELING\_ACK accept the request
* Server sends a TUNNELING\_REQUEST containing data reception for client
* Client sends a TUNNELLING\_ACK indicating the data is received
* Client sends a DISCONNECTION\_REQUEST for shut off current data transmission
* Server received and sends back a DISCONECTION\_RESPONSE accepting shut off connection.



**Figure 34. Connection diagram of KNX IP between server and client**

**Chapter 6**

# Conclusion

# Bibliography

**INDEX**