Comparison of Cloud IoT Platforms for Smart Metering Solution Based on NodeMCU

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Abstract: - This article describes design and implementation of a smart metering system based on cheap NodeMCU board which was connected to the cloud via smart IoT Gateway. The designed system consists of smart meter device that wirelessly transmits data to IoT cloud platform, where they are processed and analyzed. We compared two use cases that were using services from Microsoft Azure and IBM Bluemix. The conclusion summarizes advantages and disadvantages of the designed IoT solutions.

Key-Words: - Smart metering, Cloud IoT platform, NodeMCU, Microsoft Azure, IBM Bluemix

1 Introduction

Internet of Things (IoT) is one of the hottest topics right now. However, its beginning is dated with the first usage of RFID in 2000. Since this time thanks to technological progress many obstacles have been passed. It allows the rapid rise of smart devices around us. The term IoT covers physical devices, that are empowered with technologies and sensors which allows them to get data from the real world, communicate with each other through the network and act according to an evaluation of gathered data [1]. There are many examples of smart devices around us from smart barcodes using NFC to fully automated production lines, etc. [2]. In this paper, we focus on devices called as smart meters. Implementation of smart meters in households is one of the key aspects of the emerging concepts like Smart Grids and even Smart Cities.

2 Problem definition

The general idea of IoT is interconnectivity. Not only people should be able to communicate with IoT products, but IoT products should be able to communicate with each other. In the future, People will be supervisors of their IoT products and households via web applications with one smartphone or one tablet [3]. Nonetheless, the amount of data produced by various devices increases continually causing problems with remote control. Authors in the paper [4] intended to address these problems with a proposed architecture of smart gateway for data acquisition and remote control which used context-based services.

Term smart meter refers to a new generation of the system, that can measure an amount of consumed and produced electrical energy and it is also capable of two-way communication with data-central. Implementation of smart metering devices is the key aspect of emerging concept of Smart Grids. Thanks to real-time information about energy demand, electricity suppliers can quickly adapt to changes in the distribution network and utilize their network in a better way. The additional value that comes with an implementation of smart meters in households is that consumers can rationalize their behavior and reduce their energy bills.

Despite all the advantages that came with smart meters there are also some cons, like their price that is quite high, wireless communication waves that could be harmful or the fact that they can be an easy target to cyber-attacks. Today cloud providers offer excellent services for fat scalable IoT applications. Whole IoT solutions can be built and deployed in few hours. In this paper, we focus on the process of design and implementation of IoT monitoring platform based on the cheap devices and cloud services.

2.1 Smart metering and providers

In many research papers, different authors discuss various challenges of communication systems in smart grid [5], as well as candidate solutions [6] and potential [7].Development of smart distribution grid and smart meter implementation is also one of the goals of the Europe Union funded by the project called Grid4EU. According to this project, 80% of consumers with annual consumption greater than 4MWh will have installed smart meter till 2020. The actual state in the Slovak Republic is quite bad because only about 90 thousand of smart meters are already installed. If we consider that the start of Grid4EU project is dated to 2011 and the final number of smart meters that must be implemented in our country is about 600 thousand there is a long journey to fulfill this goal [3][4]. Consumers which have not already installed a smart metering system in their household but they want to reduce their electricity bills can choose one of the commercial solutions. These commercials systems usually work with clamp on current sensors or read the value from old electricity meter that is already installed. Measured values are then transferred via home WiFi network to the internet. Usually, they are also provided with an application where they can analyze their energy consumption in time, check the amount of consumed energy and total price. Some of the best known are heat2go, Neurio, Energomonitor or EmonPi which is part of open-source project openenergymonitor.org.

Table 1 Comparison of smart metering solutions

Features	Neurio	Eyedro	Energo-monitor	EmonPi	Proposed solution
Real-time monitoring	✓	✓	✗	✗	✓
Historical data view	✓	✓	✓	✓	✓
Price count	✓	✓	✓	✓	✓
Consumption forecast	✗	✗	✗	✗	✓
Reports customization	✗	✓	✗	✗	✓
Notifications	✓	✗	✗	✗	✓

Another problem that lies within smart metering systems implemented by energy distribution companies is that data from a smart meter are collected in 15-minute intervals. Regarding smart meters provided by commercial providers, the smallest latency between measurement and data visualization is 15 seconds. However, for better appliance identification or accurate energy consumption prediction nearby real-time measurement and visualization is needed. For this purpose, we designed and implemented our embedded non-invasive device which can be considered as smart meter substitute. Measured data are sent and consumed by cloud services in 5-second intervals. This should provide better data for identification of appliances and entire system should be more reliable, fast and scalable.

Privacy concerns are very important to the future deployment of smart metering systems too. More and more amount of data collected from future smart meters will be collected. Smart meter users need to be sure that their data is secure. Authors in [8] attempted to address the smart metering privacy issue by anonymizing the identity of high-frequency metering data through an escrow service.

3 Design and implementation of IoT smart metering solution based on NodeMCU

In this chapter, we describe the smart metering device that we designed and implemented. It was based on the NodeMCU board which is cheap IoT developing platform. We used the same device for both case studies. The only difference was in the main program, which was running in our device, where we changed connection strings to selected IoT platforms. Our device was monitoring electric current every 5 seconds. Then it was sending data via WiFi connection to specified cloud IoT platforms where wi visualized real-time and historical data.

Our concept (Fig.1) of the IoT solution for smart metering should collect data, store them in a data warehouse and provide powerful tools for visualization of received data.

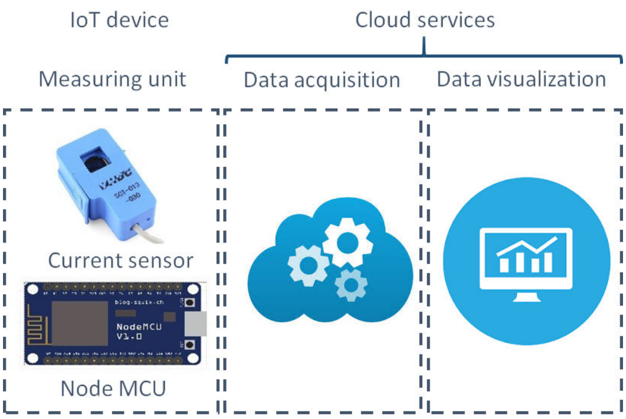

Fig.1 Three main components of proposed metering system

Concept consists of three main parts. We can summarize this solution into following way:

- The first one is the IoT measuring unit is
- based on the clamp with a sensor measuring electric current and development board.
- The second part of our concept is cloud services that are used for data acquisition, transformation and loading into the database.
- The last, third part of our proposed solution is business intelligence portal for analyses and visualizations of collected data.

3.1 Measuring unit

Authors in the paper [9] proposed Home control module based on Arduino board. They summarized advantages and disadvantages of designed module Our measuring unit is represented by SCT-013-030 clamp on non-invasive current sensor (specifications in Table 2). We choose 30A sensor because of main flat fuse is rated at 25A, so current should not exceed this value. To gather and send data we used NodeMCU Devkit v0.9 which has a built-in ESP8266 module for WiFi communication. We have connected current sensor to analog input of the NodeMCU board. This analog input has 10bit precision and can be set to working range 0-1V. This means that current can be measured in 30mA steps.

Table 2 Current sensor specifications

Rated input	0-30A
Rated output	0-1V
Accuracy	±1%

To calculate consumed apparent power, we used a simple formula:

$$P = \sum_{sop}^{eop}(U_{const} * I_i * \Delta t) \qquad (1)$$

Where U_{const} is calculated electric potential or voltage in volts, I_i is measured electric current in amperes, Δt was time period of measurement. Then we calculated sum of these intervals where sop is start of period and eop is end of the period. After final calculations we got *P,* which is electric power that was consumed in Wh (watt hour).

3.1.1 Setting time period of measurements

The proposed platform collects data from sensor and sends only important data to the cloud. In the gateway, we are creating digital twin of real world. There are methods that filter data based on the rate of change and information entropy. We also considering the use of other more secure IoT networks such as LoRaWAN. Conceptual framework of smart IoT gateway that focuses on data acquisition was published at conferences APMS 2016 [11] by our team. Thanks to this advanced data acquisition, we can save network traffic and thus costs for cloud services.

3.1.2 Measurements of electric potential in the grid

In this case, we must know the amount of instant current and voltage. The measure of instant current is provided by the used sensor. According to the Slovak technical standards (STN EN 50160:2011) there is guaranteed voltage 230V with tolerance ±10V in Slovakia [10]. The voltage changes throughout the day because of the changing load in grid. In fact, that our device was not capable of measuring the instant value of voltage, we used digital multimeter UNI-T UT61B to measure and collect voltage range during working days and weekend during the period of one week. Measured ranges of voltage were between 235V and 242V during a working day and 233V to 240V during a weekend. We calculated the average voltage and set the constant value of 237.5V for apparent power calculation to refine our measurements. According to our computations, this constant value should not make more than ±2% inaccuracies in final output. The block diagram for measuring unit can be seen in figure (Fig.2).

3.1.3 Smart IoT Gateway

The proposed platform collects data from sensor and sends only important data to the cloud. In the gateway, we are creating digital twin of real world. There are methods that filter data based on the rate of change and information entropy. We also considering the use of other more secure IoT networks such as LoRaWAN. Conceptual framework of smart IoT gateway that focuses on data acquisition was published at conferences APMS 2016 [11]. Thanks to advanced data acquisition, we save network traffic and costs for cloud services.

3.1.4 Program for data acquisition

The program for the measuring unit starts right after we plug development board to the socket. For powering up the device we used 5V adapter. After device successfully setup and connect to a specified WiFi network, it initializes MQTT communication with IoT Hub cloud service running in Azure. If communication is successful device get actual time from NTP server, measure value of current and calculate the apparent power. Measured data are then serialized to JSON format and sent to IoT Hub. This loop in 5-second intervals is repeated while the board is plugged. Whole communication is encrypted using Shared Access Key for authenticating in IoT Hub service.

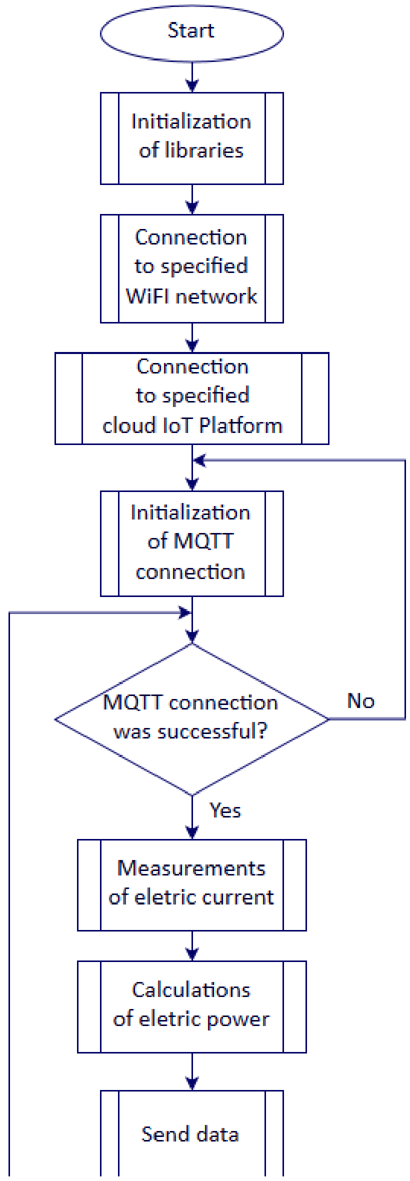

Fig.2 Algorithm of the program used for measuring unit program

4 Comparison of Cloud IoT Platforms

As we mentioned before, a smart meter could be considered as IoT device. Huge volume and velocity of sensor data need stable infrastructure and it is very common that IoT systems are running in a cloud environment. Nowadays we have a lot of cloud platforms that provide us their services but not all of them are focused on IoT. Before we started developing our smart metering system we made some analysis of IoT dedicated platforms. The main purpose of these platforms is to provide tools and services for secure communication, device connectivity through their own SDK's, device monitoring and management, analysis and visualization of gathered data or some pre-built solutions for faster application development and deployment. There are leaders like Microsoft Azure, IBM Watson IoT platform or Amazon Web Services IoT on the market but also many others like GE with their predict platform or PLC's platform called Thingworx.

4.1 Use case I. – MS Azure

After test of IoT platforms we have summarized our experiences and we decided to choose Microsoft Azure platform due to its rich documentation and service offerings that fit our requirements. Used services and process of smart metering solution can be seen in figure (Fig. 3).

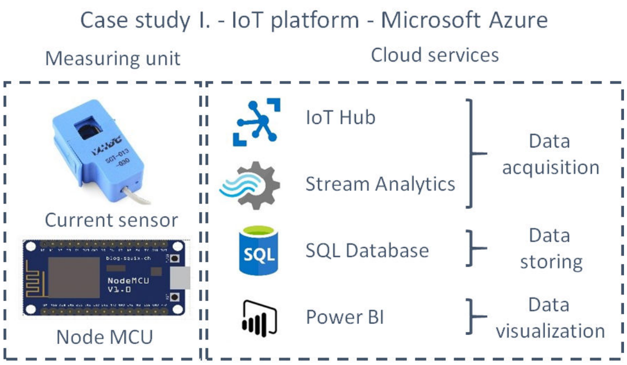

Fig.3 Concept of smart metering solution with use of Microsoft Azure services

Table 3 List of Microsoft Azure services used in use case I.

Name	Features	Pricing / month
IoT Hub	500 devices, 8000 msgs/day	0.00 $
Stream Analytics	1 unit x 732 hours	87.84 $
SQL database	100 DTU, 250GB	29.52 $
Power BI	1 user / month	9.99 $

4.1.1 Data acquisition

IoT Hub service is used here as a protocol gateway, providing us secure and reliable communication with measuring unit. It doesn't have any storage so that gathered data must be consumed by another service. For this objective, we used service called Stream Analytics. In this point, Stream Analytics job is used in two ways:

- Publish data to Power BI tool for real-time visualization and save it to SQL database for further analysis.
- Aggregate values in 15 minute and 1-hour windows and publish it to SQL database for further analysis.

By this way, we can visualize real-time data from streaming dataset and make reports from data stored in our database. On the following picture, there is a flowchart of our concept. We present cloud services that were used for data acquisition, storage, and presentation. The whole configuration cost approximately 127 USD per month (December 2017), but more than 50 clients could be connected simultaneously [13].

4.1.2 Data visualization

Data without its representations doesn't bring any value. So that we decided to visualize measured data in a user-friendly form. The main goal of the whole smart metering system is to provide information about energy demand in real-time but it also needs to give us information about summarized values like total consumption and price for consumed energy. Designed system fulfill both these requirements and provide additional functionality like a prediction of consumption for next day and notification about overconsumption.

For purpose of data visualization and modeling,

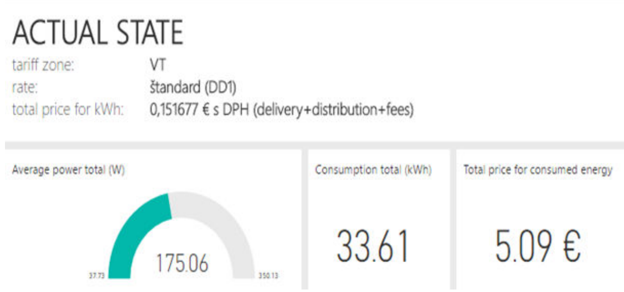

Fig.5 Use case I. - Actual state panel

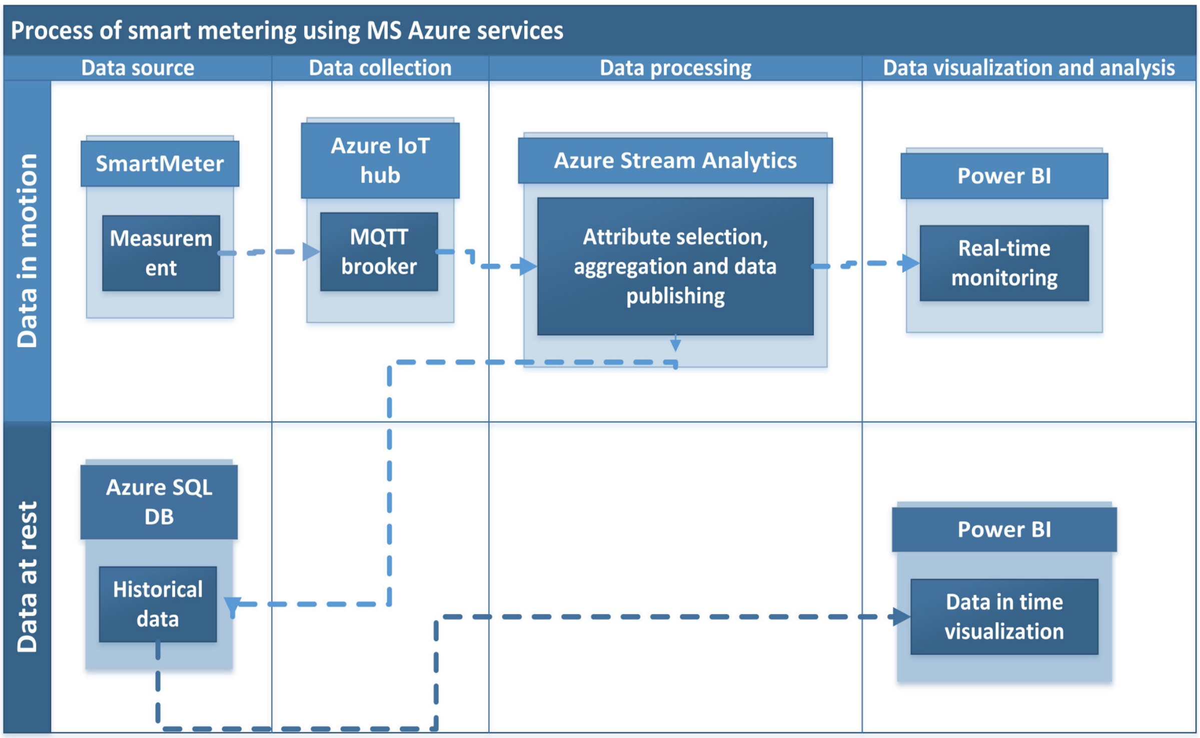

Fig.4 Process of smart metering using MS Azure services in use case I.

we used Microsoft Power BI tool. Power BI is part of Microsoft Office package and it can be used for free with a capacity of 1GB. Another advantage comes from easy integration with Microsoft Azure cloud services and intuitive user-interface, what makes it as the right decision. Our vision was to create default dashboard for the smart meter which will provide all the basic information about actual state and consumption process in time. The designed dashboard is built from Power BI reports which are pinned to the main view. It is fully customizable to consumer requirements.

The first part of default dashboard is information panel about the actual state of energy consumption as can be seen in figure (Fig.5). The consumer is informed about the tariff, provided service and total unit price for 1kWh of consumed energy. It also contains information about average apparent power represented by gauge chart, the total amount of consumed energy in kWh and corresponding price. Gauge chart has implemented listener which informs consumer if average apparent power rises over defined threshold via email.

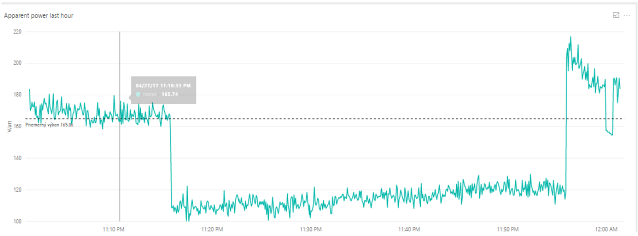

Fig.6 Use case I. - Real-time monitoring of the apparent power

Next part of default dashboard is represented by line chart that models the process of apparent power in time for last hour. Data shown on the chart (Fig.6) are in real-time and values are rendered in 1-hour horizon with 5-second refresh interval. It also has highlighted line for average apparent power so that consumer knew if his consumption is all-right or not. Latency between measurement and data visualization is less than 2 seconds.

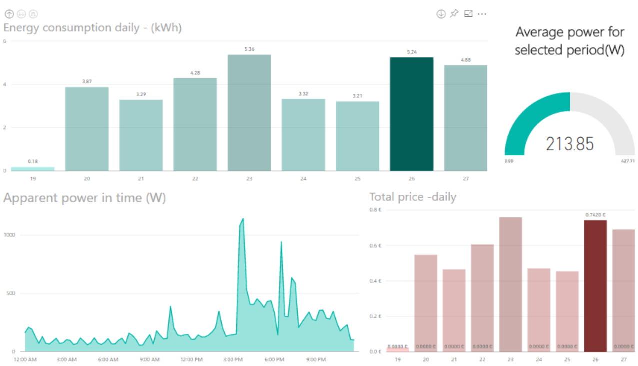

Fig.7 Use case I. - Daily report of the energy consumption

The last visual of default panel is represented by bar graph that provides information about total energy consumption in kWh in daily view in one month horizon (Fig.7). After clicking on the visual in dashboard, consumer is redirected to whole report. It is enriched with line chart of apparent power in time, gauge chart for average, minimum and maximum power and price for consumed energy on daily basis. Another added value for this report is that consumer can move in time dimension hierarchy and watch his total consumption not only in daily but also monthly, quarterly or yearly aggregates. Visuals dynamically react on consumer's day or period selection.

4.2 Use case II. – IBM Bluemix

As second IoT platform we decided to choose IBM Bluemix platform. Moreover, IBM Bluemix was one of the best rated providers for Enterprise Application Platform as a Service in the March 2016. After consultations, we have specified two services that we were used for our concept. This services are summarized in the following figure. We used IoT platform for data acquisition and IQP for visualization of collected data.

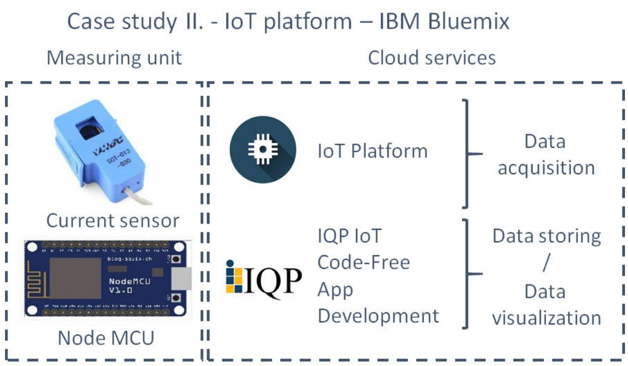

Fig.8 Concept of smart metering solution with use of IBM Bluemix services

Table 4 List of IBM Bluemix services used in use case II.

Name	Features	Pricing / month
IoT Platform	500 devices, 200 MB /month	0.00 $
IQP IoT Code-Free App Development	3 devices 10 app users	0.00 $

4.2.1 Data acquisition

IoT Platform for IBM Cloud enables quickly and securely register and connect devices and gateways. This versatile toolkit includes gateway devices, device management, and powerful application access. By using Watson IoT Platform, users can collect connected device data and perform analytics on real-time data from their IoT projects. We registered and connected our device via MQTT protocol. It was sending JSON messages with values of consumed electric power. After successful configuration we connected IoT platform with service for data storing and visualization. By this way, we can visualize real-time data from streaming dataset and make reports from data stored in our database. The whole configuration was based on free versions of cloud services (October 2017) [13].

4.2.2 Data visualization

As in the previous solution, we tried to build as similar application for data visualization as it was possible. We used service from the third party available in Bluemix called IQP IoT Code-Free App

Development. IQP is a unique development tool that anyone, even non-programmers, can use to quickly create code-free applications for the Internet of Things and Industrial IoT [13]. IQP offers a complete development solution, from connectivity with sensors and control devices to app customization and design templates. It reduces costs and Time to Market for product software. In IQP users can quickly and easily build applications using a web-based visual programming interface and drag & drop operation with ready-to-use design templates. The code-free applications are fully optimized to be viewed on all mobile phones, tablets, and PCs.

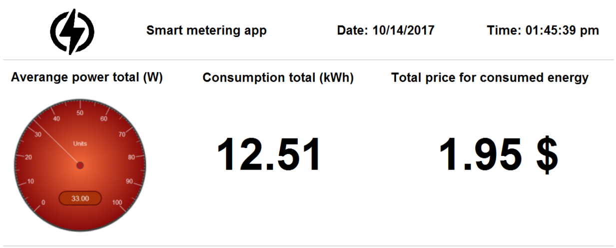

Fig.9 Use case II. - Actual state panel

Similarly, as in the first use case, the first part of the web application is information panel about the actual state of energy consumption. The consumer is informed about the average power, consumption, and price of the electricity.

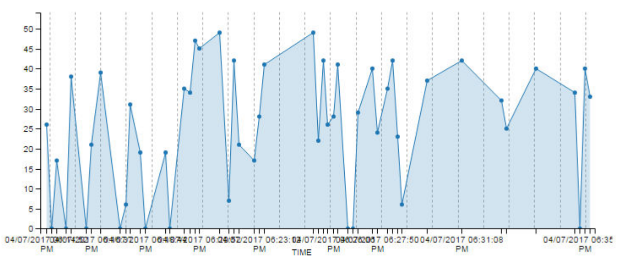

Fig.10 Use case II. - Real-time monitoring of the apparent power

Next part of the web application from the second use case was a chart that models the process of apparent power in time for last hour. Values in the chart, shown in the (Fig.10), are rendered every 5 seconds in 1-hour horizon. We have measured latency between measurement done by our IoT device and data visualization. This latency was approximately 7 seconds.

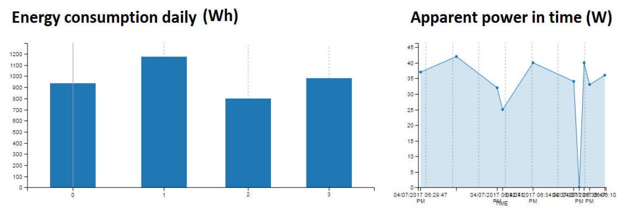

Fig.11 Use case II. - Daily report of the energy consumption

The last visual of default panel is represented by bar graph that provides information about total energy consumption in kWh in daily view and second chart shoving energy consumption of last day.

4.3 Evaluation of both use cases

In this subchapter we summarize and compare features of both use cases. Use case developed in MS Azure is more complicated. It offers Business intelligence functionality, but it cost more. On the other hand use case developed in IBM, Bluemix was created in just a few hours, and it provides essential features and runs for free. These conclusions are summarized in the following table.

Table 5 Comparison of our use cases that were using cloud IoT platforms from Microsoft and IBM

Features	Use case I Microsoft Azure	Use case II. IBM Bluemix
Real-time monitoring	Avg. 2 seconds latency	Avg. 7 seconds latency
Historical data view	Yes SQL database	Yes 30 days (Free version of IQP)
Price count	Yes	Yes
Consumption forecast	Yes ML model Power BI	No
Reports customization	Yes	No
Notifications	Yes	No
Time needed to develop solution	16 hours	8 hours
Price	Approx. 127 $ / month (50 users)	Free

5 Implementation of our concept

After Evaluation we decided to implement use case I. that was using MS Azure services. Designed system was deployed in a flat house as can be seen in figure (Fig.12). Measured data shows power consumption incomplete circuit.

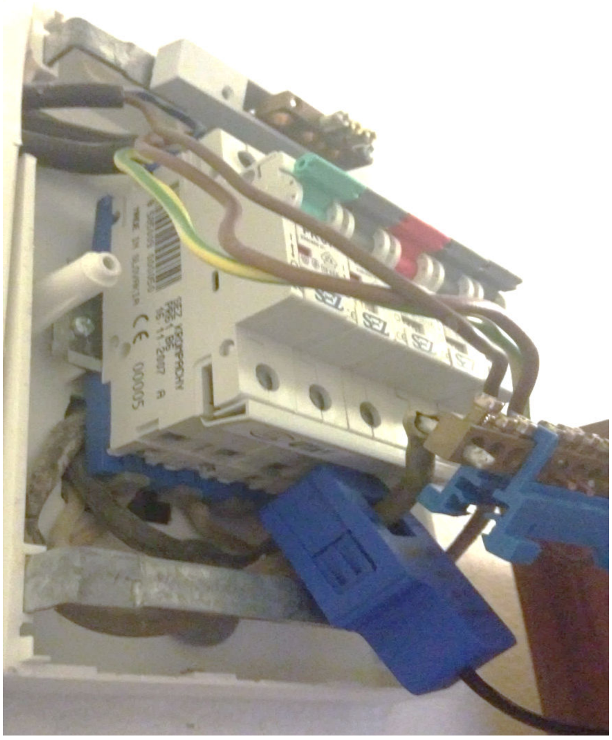

Fig.12 Sensor deployment on flat house phase wire

After few days of continuous measurement, we found out that electricity usage shows a strong periodical pattern. In measured data can be seen a difference between day and night, workdays and weekends. We also identified running appliances and its consumption patterns. On the picture (Fig.13) there is, for example, different visible characteristics of a freezer, coffee, and washing machines. It means that measured data can be used for further analysis, for example identifying running device according to its consumption pattern or energy consumption prediction for the selected period. Also, the fault detection can be based on these patterns. For example, if the pattern of the fridge is changed or is not present in collected data, there can be an assumption that fridge is faulty or need to be checked.

The accuracy of the presented solution was also tested. We compared values from electricity meter installed by electricity distribution company with values of our solution. In one month period, the overall deviation from real power consumption was less than 2%; it represents difference about 3kWh per month in a household where the monthly power consumption is about 150kWh. We have also compared daily consumption of the proposed system. The maximum deviation from real power consumption in one day readings was +3.2%.

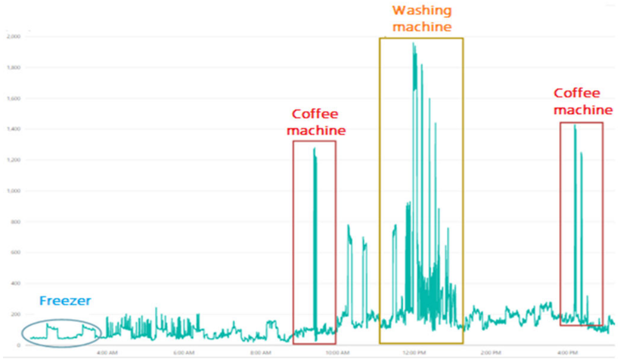

Fig.13 Appliances identified from the characteristic of the electric consumption

6 Conclusion

Implementation of smart meters in households is one of the key aspects of the Smart Grids and even Smart Cities. Today cloud providers offer excellent services for fat scalable IoT applications. Whole IoT solutions can be built and deployed in few hours. In this paper, we designed IoT device based on the Node MCU developing board. This device we connected to the two specified IoT Platforms. We decided to use Microsoft Azure and IBM Bluemix services for these purposes. We provide the summarization of concept and our results. Finally, we decided to implement the solution based on Microsoft technologies. Thanks to this architecture we can monitor real-time consumption of electric energy, and we can predict future consumptions. Moreover, with quality data stored in SQL database, we are planning to focus on appliances classification.

We developed our own IoT device and thanks to 5 second period of measurements we can easily see differences in apparent power of various appliances. On the following picture (Fig.14) are characteristics of appliances.

Coffee machine

Washing machine

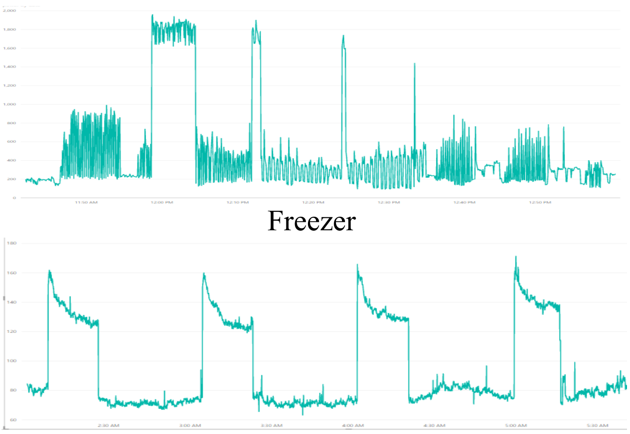

Fig.14 Detailed characteristics of appliances

7 Future work

In future work, we are planning to test different sensors and development boards for more accurate results. We are also planning to focus on the Smart IoT Gateway where we want to implement more complex algorithms for data acquisition. Thus, save costs for cloud services and try to understand the collected data better.

The efficient use of resources is a matter of great concern in today's society, especially in the energy sector. Effective use of resources is one of the critical aspects of Smart Grids and even Smart Cities. Therefore, in the future work, we want to implement classifiers based on machine learning methods such as deep learning for an automatic identification of appliances from data collected by our metering system. Authors in [14] also used data collected from smart meters to identify users to groups and based on that they tried to predict energy consumption. We want to do so with our IoT solution. In this context, we want to propose a system which will extract value from the collected data, and it will identify the appliances belonging to the smart environment using advanced machine learning techniques.

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