with Ethernet shield, but EtherDue has integrated Ethernet interface.

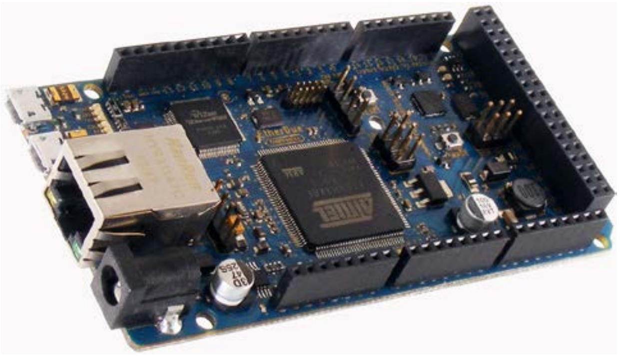

Fig.5 EtherDue

Sensors and actuators for thermal and light systems was developed during this phase. The thermal system consists of temperature sensors, air condition. Scale model of air condition (Fig.6) is made from peltier, passive and active coolers. Peltier is between two passive coolers (heatsinks). Heat transfer ensures active coolers (fans). The light system consists of LED strip, blinds, and photo-resistors.

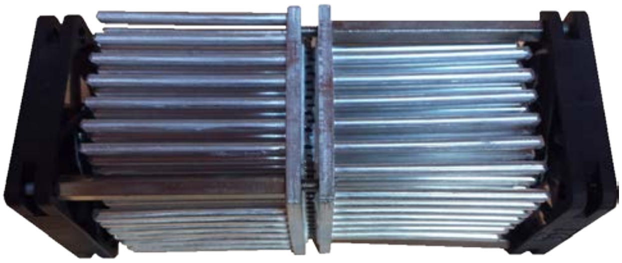

Fig.6 Air condition for our model

We developed PCB (printed circuit board) with the socket for EtherDue (Fig. 4, Fig. 7), this socket is fully compatible with Arduino. PCB is connected via copper cables with others our PCBs and connectors blocks. The PCB was created for better handling and connecting cables to the controller (EtherDue or Arduino).

Fig.7 PCB with socket for EtherDue

H-bridge Controller (Fig. 8) is PCB developed for thermoregulation (peltier) and regulation of blinds (motors). This PCB allows connecting actuators to the controller with power supply from 12 to 40V and maximum current 33 A. H-Bridge Controller is placed in a standardized box for the switchboard.

Fig.8 H-Bridge Controller

MOSFET power stage (Fig. 9) with 6 channels is developed for LED strip and fans on air condition. The maximum supply voltage is 30V DC and current consumption 5A. Controller is placed in the same standardized box for the switchboard.

Fig.9 MOSFET power stage

Mentioned PCBs can be used on others devices with power supply from 12 to 24 Volts. During this phase was developed many others PCBs and improvements of sensors and actuators. Two power supply is installed in the switchboard, the first supplies 12V, and the second supplies 24V. The physical model is shown in figure Fig. 10.

Fig.10 Physical model CASTLE

4.3 The Third Phase

When we have constructed the model with sensors, actuators, switchboard and we have simulated the thermal system, we can program this control to the cloud system. This control is programmed as a service through Microsoft Azure. Using the same service is also controlled lighting system. This phase has many options of realization. These options are described in the next chapter named *Models of Control*. This service will be enriched by control of IoT products developed in the fourth phase.

4.4 The Fourth Phase

At this phase will be designed other IoT products, which will use in the project. Priority will be to search existing IoT components for household, but their number is still low, so this design will be extended.

The extended part of the design will propose devices individually from appearance design, via electronic proposal, to material design. Finally, all proposals will be implemented and installed on the model of the household. These devices will be connected to the cloud from Microsoft Azure. Communication protocols will be set and programmed. Regulation and control will be programmed for designed IoT devices (products, things). Creating a web HMI (human -machine interface) environment for the user will be also necessary (in addition to the necessary services for control). This web page (HMI) will be part of the cloud system creation. For a long time, HMI is not just a matter of industry. Search, design, and programming of possible interactions between elements in the home will be part of this phase. At this phase, we are still working. Many sensor and actuators make possibilities for multi-agent systems with interactions.

5 Models of Control

The first idea was to keep the whole control of house on the cloud. This model of control works, but household becomes dependent on the Internet connection. If the provider can guarantee non-stop connection to the Internet, then control can stay on the cloud system.

In 1961, John McCarthy defines utility computing (nowadays cloud computing) and he compares this utility computing with electricity and water. His idea was that in the future we will buy computing power as electricity or water in the home. [3]

With this mentality and after few years, people can be dependent on the remote cloud-based systems and the Internet, as now on electricity and water. So we decided not to leave everything to the remote and public cloud and we come with three options:

- control and HMI through the public cloud,
- control and HMI through the private cloud,
- control and HMI through the hybrid cloud.

Previously, often was mentioned service for control in this paper. These services can be named CaaS (Control as a Service). Classically, cloud services are divided to:

- IaaS (Infrastructure as a service),
- PaaS (Platform as a service),
- SaaS (Software as a service).

CaaS is software as a service, which is specialized for control. CaaS is not defined as a basic group of cloud services, yet. We are not the first, who use term CaaS, before us use this term [4], [5]. Imagine an environment where IoT devices perform only basic computing and cloud services as the CaaS perform control and manage interconnection between IoT devices. In our opinion, this is ubiquitous computing in the wider sense. Ordinary users will feel ubiquitous computing, but they do not know where ubiquitous computing is. They do not be interested where it is, because it will be ubiquitous.

5.1 Control and HMI through Public Cloud

We use services of Microsoft Azure for control and HMI through the public cloud. Microsoft Azure has special services for IoT products. These services are IoT Hub, Event Hubs, Stream Analytics, etc. There are other companies offering similar services, for example, IBM with IBM Bluemix, Amazon with Amazon Web Services.

We have implemented three types of architecture:

- Raspberry Pi as IoT gateway with operating system Windows 10 IoT core,
- EtherDue communicates by HTML requests with the cloud system,
- EtherDue communicates by MQTT or AMQP with the cloud system.

The first architecture was presented at Microsoft IoT Hackathon by our research group. All IoT devices are connected to Raspberry Pi by Ethernet, WiFi, Bluetooth, and others interfaces. Raspberry Pi sends all information from sensors to public cloud by MQTT protocol via service named Event Hub. Our solution uses Microsoft Azure as public cloud. This information is transformed by service Stream Analytics. Then it is stored in the NoSQL database, and presented by the web page (HMI). The last step sends information to devices (actuators) to take action. Described scenario is shown in Fig. 11.

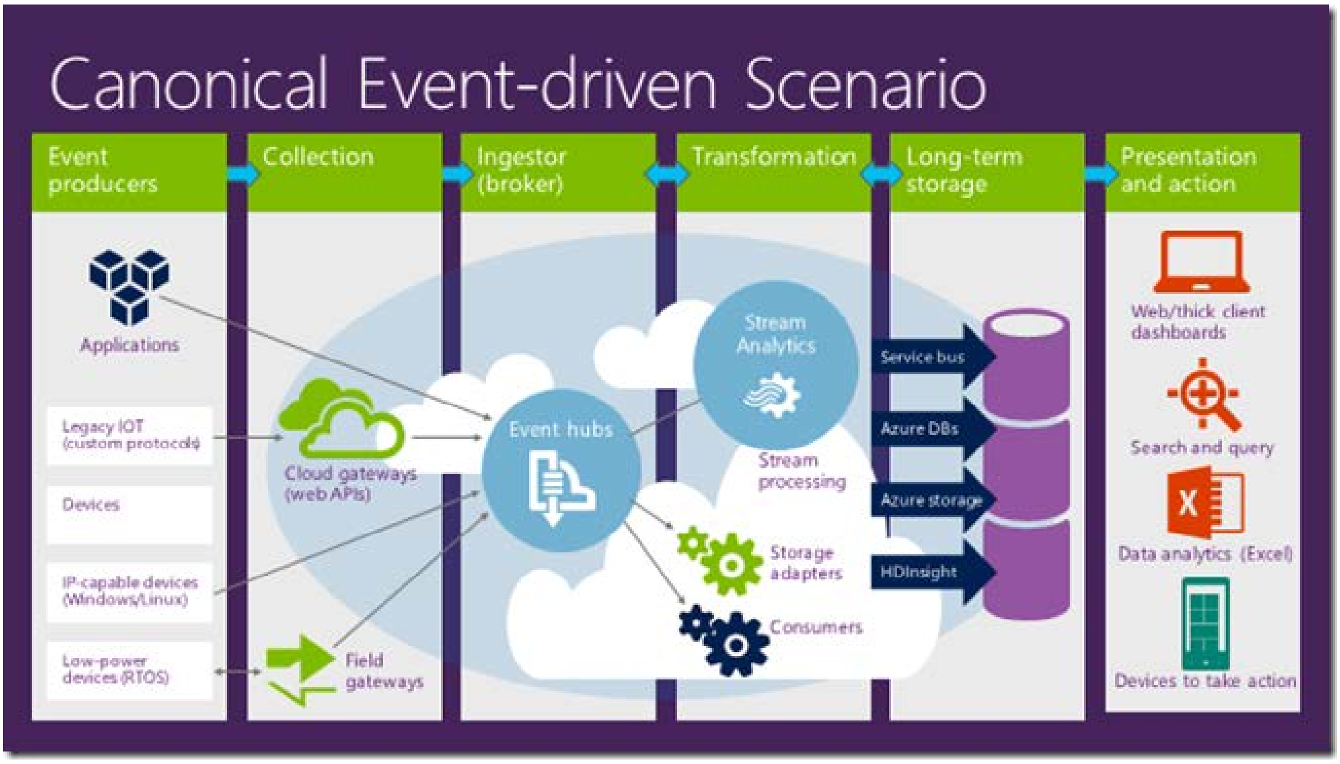

Fig.11 Canonical Event-driven Scenario [13]

The second architecture is using on our household model. EtherDue collects data from all devices in the house. This data is sent to the public cloud as an HTTP request. Cloud this request evaluate: store date to the database, dynamically change HMI web page, and calculate control variables for actuators in the house. These variables are sent back to EtherDue as an HTTP response.

The last architecture is similar to the first architecture, but EtherDue is used without Windows 10 IoT Core. The architecture use MQTT or AMQP protocol, Event hubs (for example IoT hub), Stream Analytics, etc. (Fig. 11). This last architecture is the best according to latency. We used the second architecture, because this model is used for education, and RestAPI is a more general solution than Events hubs from Microsoft.

In this solution, web page (HMI) and control algorithms are running on the public and remote cloud system. All information from sensors is sending to cloud and all information to actuators is receiving from the cloud.

This solution is dependent on the Internet connectivity fully. Part of HMI (light control) can be seen in figure Fig. 12.

In this case, the provider of cloud services is responsible for security. Safety is in the hands of an integrator (or user) that installs IoT products, programs control and HMI web page for the household.

5.2 Control and HMI through Private Cloud

User (or integrator) can build own server, which will control user's household. If the user uses classical server or personal computer, then the solution is not economical because a classical computer has average power consumption 200 W (from 70 W to 500 W), that is mean 1700 kWh per year. If the user uses a notebook as a server, then average power consumption is 50 W that is mean 425 kWh per year. But when is used Raspberry Pi (Fig. 13), then power consumption falls to 2 W that is mean 18 kWh per year.

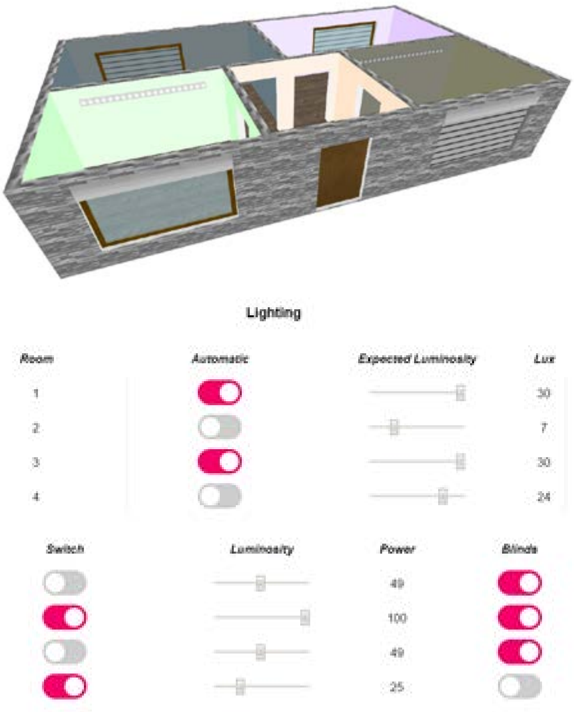

Fig.12 Part of web page (HMI)

When we want to use the home server, we need public and static IP address. Most Internet providers use dynamic or private IP address because they want to provide the Internet to many people with small address space.

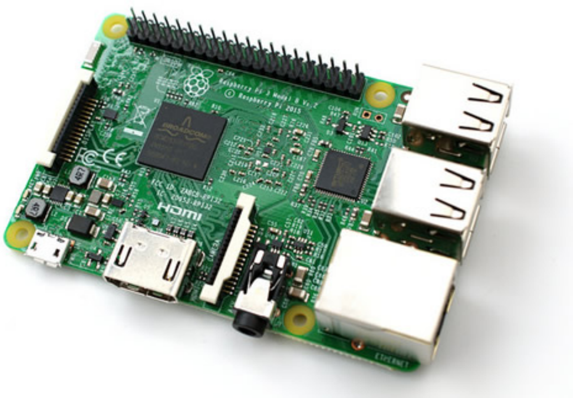

Fig.13 Raspberry Pi model 3

If we use the private address, then control will function only in local home network and the user can not control house by HMI outside of this network. If we use the dynamic address, then we have to know our actual address every time, when we want to connect to our house. If we have static and public IP address, we can implement our solution of control by the private cloud. Control algorithms and HMI web page are programmed on Raspberry Pi and every IoT product has to communicate with Raspberry Pi. Raspberry Pi is the web server and the household controller at the same time. This solution is not dependent on the Internet connectivity. When Internet connectivity is lost, the user can not connect to HMI outside the home network, but control is running.

Security and safety are in charge integrator in this case.

5.3 Control and HMI through Hybrid Cloud

This model has distributed control algorithms and HMI web page. Control algorithms are running on the private cloud and HMI is running on the public cloud. Static and public IP address is not important because communication between clouds provides HTTP requests. Private cloud is an HTTP client, which is sending requests to HTTP server (public cloud) every sample time.

Controller (private cloud provides CaaS) may not be the computer, but the controller can be Arduino with Ethernet or WiFi shield, EtherDue or any single-chip microcontroller with Ethernet or WiFi. HMI web page is running on the public cloud and the user can monitor and set household from everywhere because these clouds communicate between each other.

Safety is in charge integrator as in previous options. In this case, the provider of web services is responsible for security.

The first and the third *model of control* can use IoT gateway for distribution of data, and SOA (service oriented architecture) for data acquisition and data processing. Our research group is researching and developing these technologies, what can be seen in [6], [7], and [22].

6 Research and development impacts

Thanks to this project occur development in two directions immediately: the development of IoT products and the development of CaaS for households. The web server is running on the cloud, thanks to this web can be controlled and set requirements of the household. So the user can control the particular thing at home on a tablet, laptop, smartphone or other devices which can display the web page. Such control would not be necessary to develop separately for each household.

It could develop only one service that could be joint to any household.

Mentioned process would reduce the cost of production of these smart devices and the development of control would not be directed to a specific household. A control algorithm could be used for any household.

6.1 Benefits

Results can be divided into three groups:

1. technical or hardware solution,
2. software solution,
3. methodic.

The technical solution includes a functional model of the smart home with all installed IoT elements connected to the global Internet. This smart home with IoT elements are controlled from a web browser and it is regulated and controlled remotely. The technical solution also includes various IoT elements, which was developed under the project CASTLE. Until that time, it was developed:

- thermo-regulatory elements made of peltier, heatsink, and fan,
- the system of temperature sensors,
- light system: the system of actuators (blinds, LED lights) and sensors (photoresistors),
- switchboard.

Software solution includes:

- individual firmware for IoT products,
- remote control and regulation algorithms for IoT products,
- web HMI environment running on the same platform as control and regulation of IoT products,
- algorithms of interaction between IoT products.

Methodic was mentioned in chapter *Models of Control*, where was described control and HMI through private, public and hybrid clouds.

7 Conclusion

This paper defined three models of control for IoT residential and business premises and described implementation methodic. Also, our research group built scale household model using described methodic.

The project will benefit in the social sphere, whether it will be a comfortable living, intuitive systems or price reductions of smart products. This product will benefit the production sphere since in this area may find inspiration. Also, a platform of application developed during this project foresees the significant potential for commercial use.

Project CASTLE (model and concept of system creation) has a high envisages the use in the education of the latest technology. Specifically, the education of IoT Systems, Cloud Solutions, Architecture of Industrial Information Systems, Single-chip Microcomputer, Computer Systems in Control and other studies courses dealing with the latest IoT and cloud technology.

After the successful implementation of the project CASTLE, our team wants to continue creating smart IoT rooms (laboratories) at our department. We want to move from a physical model solution to a real solution. In future, this solution can be used in real households, offices, workplaces and others residential or business premises. IoT network itself creates ubiquitous computing, but if it adds interconnection with cloud technology and CaaS, then ubiquitous computing is expanded.

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