MODULARITY Applied to SMART HOME

From Research to Education

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Abstract. Reducing energy demand in the residential sector is an important problem worldwide. This study is focused on the awareness of residents to energy conservation, potential of reducing energy and the implementation of a solution in the field of Intelligent House. This paper presents a newly designed integrated wireless modular monitoring system that supports real-time data acquisition from multiple wireless sensing units.

Keywords: Energy savings · Building monitoring system · Wireless sensor network · Xbee · Smart home · Cypress · IQRF

1 Introduction

Energy usage and its resulting impacts on our environment became one of the major concerns humanity is facing today. Depletion of fossil fuels, the impacts on the environment from mining those fuels, and the spectre of global warming exacerbated by burning them are critical reasons for us to become more responsible for the energy we consume.

As one report of The Intergovernmental Panel on Climate Change shows, the industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 379 parts per million in the last 150 years. The panel also concluded there's a better than 90% probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years. According to this report the rate of increase in global warming due to these gases is very likely to be unprecedented within the past 10,000 years or more [1].

Generating energy requires precious natural resources, for instance coal, oil or gas while reducing energy consumption has lots of benefits – we can save money and help

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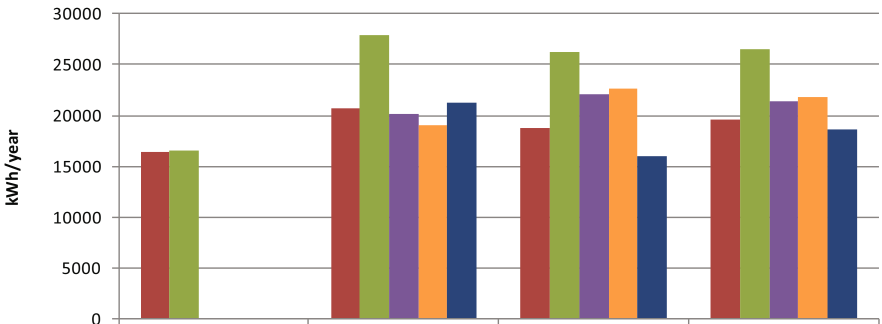
protect and preserve our environment. Therefore, using less energy helps us to preserve these resources and make them last longer in the future.

In the light of these facts above, we believe energy must be in future a concern of all citizens and new tools must be created in support of our environment, starting even from every household.

It must be noted that energy service demand may also reflect changes in the level of comfort and lifestyle requirements of households. Specific energy consumption is defined as the energy required to maintain a particular level of energy service in households. It is a modelled alternative to energy intensity, and takes account of changes in demand for individual energy services (such as level of household comfort or hot water use), and helps to remove the impact of higher and lower external temperatures on energy use.

In this paper we focused on energy consumption in Belgium and Netherlands. According to VEA Flemish Energy Agency, the average energy consumption of a person per day is 50 kWh and from that 71% represents heating [2].

Let`s take into consideration that most companies involved in reducing energy consumption and environmental pollution try to minimize energy consumption by raising the efficiency of their systems and improving the buildings (heating devices manufacturers such as Daikin or Viessmann, campaigns like the US Solar Decathlon), or increasing user's control over their systems (Google's Nest, Smappee, smart metering systems of Daikin and Veissmann). The disadvantage of these systems is high cost and significant changes in the construction of the building (Fig. 1).



	Brussels region	Flemish region	Walloon region	Belgium
natural gas	16480	20712	18733	19644
fuel oil	16604	27902	26176	26489
wood		20202	22099	21350
coal		19110	22582	21803
Propane		21234	15946	18608

Fig. 1. Average total energy consumption (kWh/year, dwelling) per principal energy source per dwelling per region and for Belgium (survey results) [2]

Figure 2 describes the heating losses starting from the boiler till the end user. As we can see there are three main factors that are involved in the heating process: the first two ones are the Boiler and the Building, components that most of the companies mentioned above are dealing with; the 3rd one, and we might say the most unpredictable one is the third one, people's behavior. In this research we will focus to provide a technological solution, an energy monitoring system which can engage people in a more responsible way to save energy in the cope of lowering energy costs.

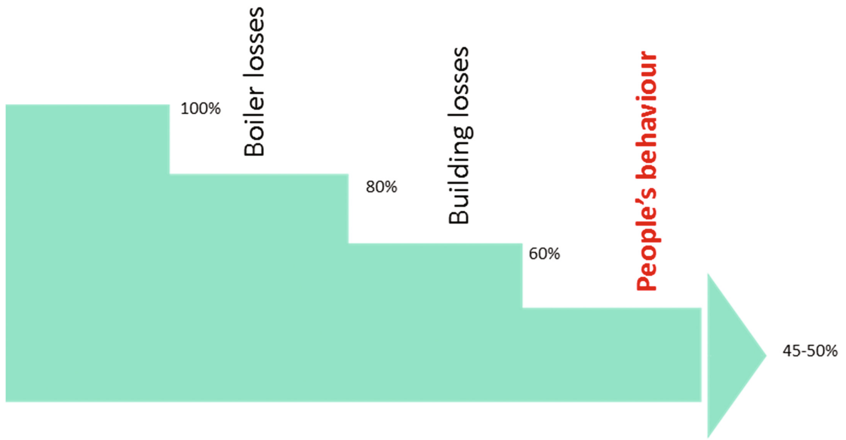


Fig. 2. Energy losses in a building

To address the above issues, monitoring the habitant's behaviour and informing them about their own way of using energy, this paper describes such a monitoring system designed to validate, collect and connect the users with the status of the building. During our study we compared different ways of building a wireless modular system (here we focused on the wireless technologies available on the market) and with the information collected we had identified and validate how the flow of input data collected can contribute in habitants perception of using energy.

Regarding the hardware, our focus is to provide a reliable and also cheap solution for first validation stage. As to the modular configuration and the limits of the system. During our research we evaluate several scenarios and validate our assumptions by case studies conducted in two buildings.

2 Energy Monitoring Architecture

Our aim during the research is to find the best solution for creating and testing a monitoring system dedicated to student house owners. The focus of the system is on the heating structure and heating losses, which is the most expensive cost for our market. Because our modular system should not affect the building structure, heating pump structure and should be easy to install, the following are required:

- a wireless communication structure
- collecting information of air flow in each room.

In order to identify the heating losses it is necessary to observe the temperature of the heater, temperature of the room and the status open/close of the window. This information should be enough to predict the thermodynamic flow (Fig. 3).

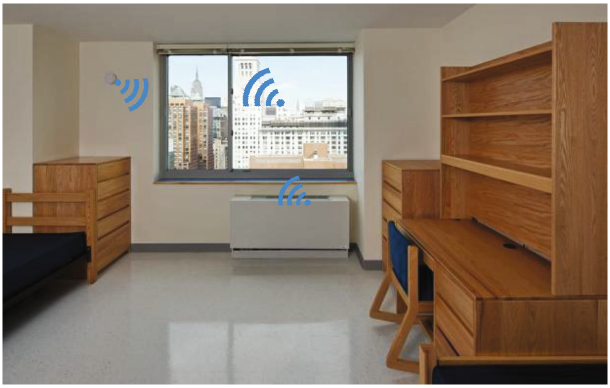


Fig. 3. Room scenario

In order to be able to validate the requirements mentioned above and also to validate the principals of creating a modular system for this purpose we defined several hardware requirements for the alfa product: low power wireless communication protocol, two temperature sensors and one contact sensor.

3 The Architecture of the System & Operation Pattern

Figure 4 presents the complete structure of the alfa system we are proposing. The flux of information is marked with the blue arrow and is composed by:

1. The "Gateway" described above - the link between the building and the cloud (formed by Xbee module, the main logic board);
2. The "Sensor" – 2 temperature sensors, 1 contact sensor, the link board and the Xbee module;
3. The "Cloud" – database;
4. User interface – website.

A full descriptions of the elements mentioned above and also the role of each of them, please refer to the full paper "Evaluating the reliability and scalability of a wireless energy monitoring system in buildings" [3].

In order validate the system capabilities and purpose we created an end to end data flow concept. And so the working pattern of the sensors to the users interface is described in Fig. 4. This process has 4 steps:

1. Starting with the sensors, every 30 s we collect samples from the two temperature sensors (TMP36) and the contact sensor. Through the Xbee Explorer the data is

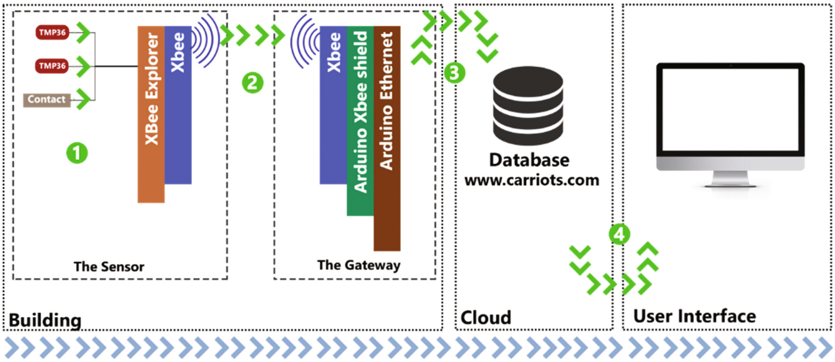


Fig. 4. System architecture & description of the operation pattern

streamed to the Xbee module. The Xbee module packs data in frames and renders the information ready for the transmission.

2. The frame is send wirelessly to The Gateway. Acting as a coordinator, the Xbee module receives the frame and forwards it to the Arduino Ethernet Board through the Arduino Xbee Shield.
3. The Arduino board unpacks the frame and pushes the raw data through the Ethernet port to the Carriots database to be stored.
4. After each week the data is interrelated and processed manually. The result then is placed on a website, using charts and easy to understand description.

Figure 5 Presents the first part of the System – "The Sensor", module placed in the rooms, the transmission node.

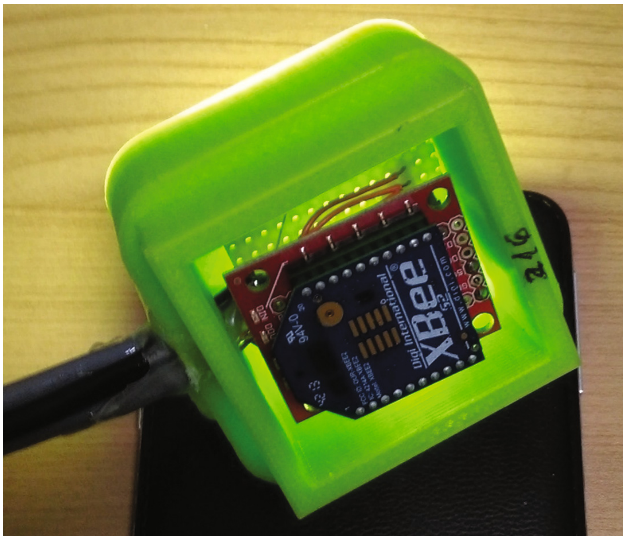


Fig. 5. "The sensor" setup – the room transmission node

4 Data & User Interface

In order to validate the system and the impact that it may have to the habitants we installed it in two different buildings. We collected data during for several weeks by not informing the habitants about the system presence and purpose and after that we inform, let them challenge each other in ways of saving energy.

During one month of collecting and stored data from each building, with the scope to present to the house owner, in an easy to understand way, the result of energy consumption in each room we developed a website including some charts and few recommendations on how to save energy was developed for that purpose.

Based on the input from our three sensors we managed not to just inform the owner on the consumption but also to evaluate the habits of the residents. Figure 6 illustrates three days consumption by data collected from one of the experimental rooms (Room4). In this case we can clearly see that the room average temperature is above the normal comfort zone of 21 °C while open window usage is not energy efficient. The tenant, in most of the situations, turns the heater at the maximum and opens the window.

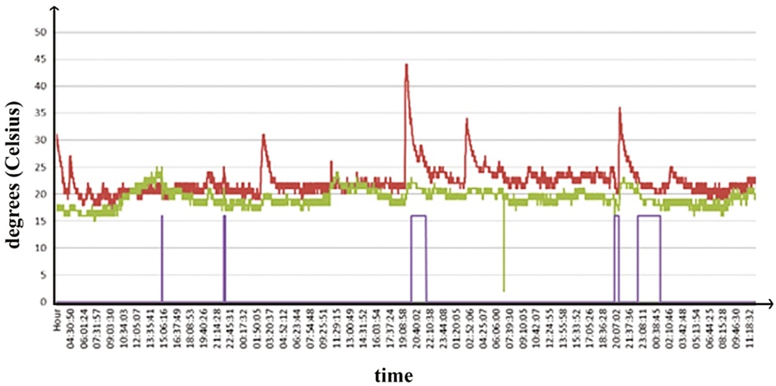


Fig. 6. Data collected from one of the devices during three days (red- heater temperature, green – room temperature, blue – window open/close).

In order to have a clear view of those habits and based on the average of the inputs, we created a profile of each user. For that we made an average of temperatures collected and movement open/closed of the window based on the time line.

Figure 7 describes user profile. Furthermore, providing to users tips on how to be more environmental friendly, we can clearly see the improvements in energy usage of the users, represented by the green line. Even if we did not get the same involvement for each tenant, as **Error! Reference source not found.** shows, it is obvious that, by concentrating more on those tips we can get better results for the future developments.

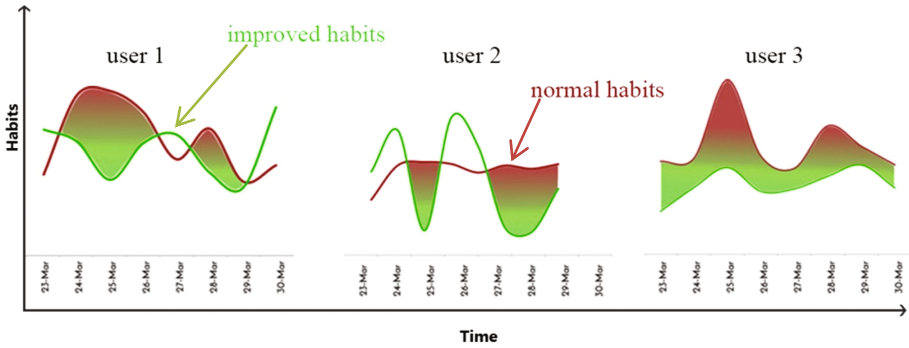


Fig. 7. User's habits profile

In order to have a better understanding of the Fig. 7 the red line represents the usage habit during the first three days of testing and the green one in the last days, after providing the tips. Subtracting the two, in Fig. 6 we can see the improvement in user habits. This result was obtained in one room, Room 4.

5 Evaluation Methodology

To evaluate system coverage and redundancy we applied several key methods to simulate and test it in a real case scenario. First we used the WHIPP tool to simulate the coverage of the system focusing on the reception sensitivity. By using this tool we were able to have a first understanding of the distance that might be between the devices. The next step is represented by a RSSI measurement conducted in a real environment. The test was made using X-CTU software, allowing us to understand which links are reliable and where an extra device is needed. The last step is a mash routing redundancy. In that phase we evaluated the system capability of establishing a new link in case of power loss. There are several key methods that we applied to test and also to determine the maximum range of our system.

5.1 WiCa Heuristic Indoor Propagation Prediction Tool

WiCa Heuristic Indoor Propagation Prediction Tool is an environment for planning wireless networks. The tool is a heuristic indoor network planner for exposure calculation and optimization in wireless homogeneous and heterogeneous networks, with which networks are automatically jointly optimized for both coverage and electromagnetic exposure. It is capable to predict and optimize the coverage and expose of an indoor wireless network (WiFi, UMTS, XBee). It is based on an advanced and experimentally validated propagation model [4]. In the Fig. 8 is presented the layout of one of the building /tasted side in the WiCa Heuristic Indoor Propagation Prediction Tool.

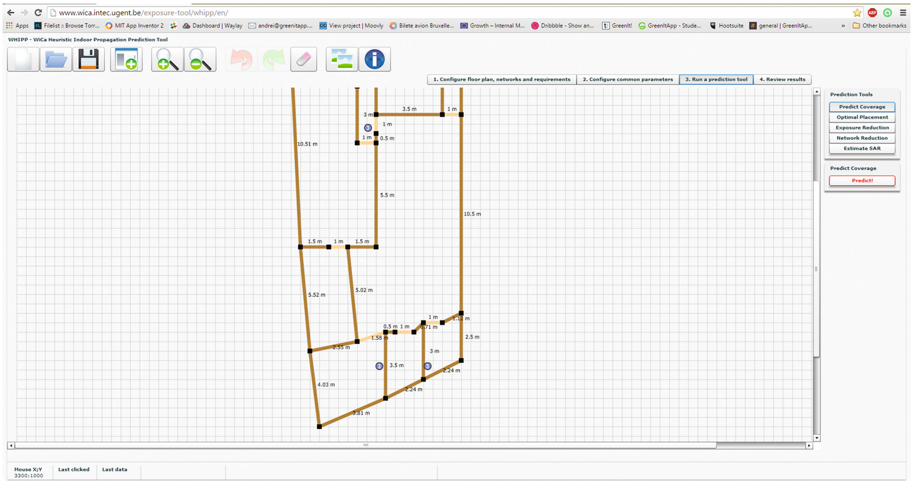


Fig. 8. WiCa prediction tool

In our case we used WHIPP tool to define the exposure limitation of the system in the tested buildings. We started by creating a plan of the building. For that purpose we used the preset material such as dry-wall, wood doors and the xbee sensors JN516x with the transmitting power of 3 dBm. The elevation of the sensors, for all the simulation, was set to 1.5 m. Taking into consideration that the position of the devices is strictly related to the heating modules in the building we focused on prediction coverage simulation.

5.2 RSSI Measurement

Received signal strength indicator (RSSI) is the signal strength level of a wireless device measured in dBm of the last received packet [5]. The main idea behind the RSS system is that the detected signal strength value reduces within the distance travelled. In free space, the RSS degrades with the square of the distance from the sender [6]. Using the Friis transmission equation, the ratio of the received power P_r (dB) to the transmission power P_t (dB) can be expressed as:

$$P_r = P_t \times G_t \times G_r \left(\frac{\lambda}{4\pi d} \right)^2$$

where, Gt(dB), Gr (dB) are gain of transmitter and gain of receiver respectively, λ is the wavelength, and d (m) is the distance between the sender and receiver. It can be seen that the larger the wavelength of the propagating wave is, the less susceptible it is to path loss. The received signal strength is converted to RSSI which can be defined as the ratio of the received power Pr (dB) to the reference power PRef (dB).

$$\text{RSSI} = 10\log\frac{P_r}{P_{Ref}}$$

Using X-CTU software, one of the XBee modules is configured as Coordinator while the other as a Router. After pairing with the Coordinator, the Router starts transmitting. Once the Coordinator has received the data packets successfully, it sends back an acknowledgment (ACK). To obtain the RSSI value the software takes the average of 100 RSSI results from 100 packets of 32 bytes each. Hence, the RSSI value is measured after sending 100 packets of 32 bytes each, and then the average is used to generate RSSI.

The distance between the Routers and the Coordinator was variable. We applied different case scenarios depending of the building where we tested the system. As presented in Figure Building A and Figure Building B we conducted static tests by placing the coordinator setup in the main hallway of each floor. The average distance between floors in case of Building A is 2.7 m and for Building B 2.3 m. For each floor setup we tested the link to each device in the system, one by one, in order to determine the relationship between RSSI values and the distances.

5.3 Mesh Routing System Redundancy

A ZigBee mesh network configuration is done automatically and flawlessly by the XBee devices. The Coordinator starts a ZigBee network, and other devices then join the network by sending association requests. As we described in the second chapter, ZigBee networks are considered self-forming networks due to their ability of self-routing.

After forming the mesh network, to relay the message from one device to another, the most optimized path is selected. However, if one of the routers becomes damaged or otherwise unable to communicate due to power loss, the network can select an alternative route.

One of the most important characteristics of ZigBee mesh networking has been its self-healing capacity, the ability to create alternative paths when one node fails or a connection is lost through mesh routing [7]. In order to test this attribute of mesh routing, we observed the elapsed time between the elimination of one path and the search and formation of another. To perform the test, we captured messages received on Coordinator from the network. Then we powered off one by one each Router until the link was disconnected. This experiment determines where a repetitive (Router) device is needed in order to guarantee the redundancy of the system.

5.4 Test Results Between the Tool and Real Conditions

Taking into consideration the results of the mesh redundancy we observed that without the device from room 2, the network cannot communicate with the device from room 1. In order to compare the results of the WIHPP tool with the ones conducted in real situation we simulated the scenario A without the device from room 2, Fig. 9b.

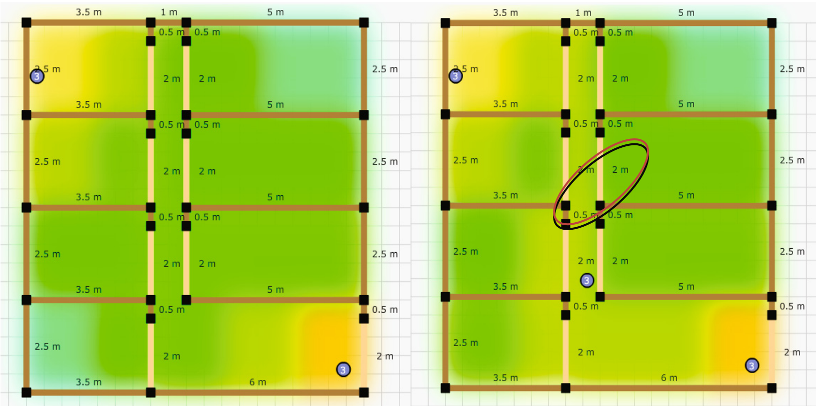


Fig. 9. (a) WHIPP simulation. (b)WHIPP simulation without device 2

Below, in Fig. 9 are presented the two scenarios: figure (a), with the device from room 2 and picture (b) without it. There is a change in color between the two simulations. The first one has a green – yellow color but the second one a darker green, marked with the red oval. According to the tool this color represents a rage of sensitivity between −44 to −50 dBm and in real situation test it will show a loss of connection.

6 Experiment Conclusions

As it was shown in this paper, the performance of the proposed system, different scenarios were undertaken in order to measure the performance of the monitoring system network, with a focus on the mesh routing redundancy and the RSSI level of the Xbee modules, comparing the results with a software simulation. The results showed that the performance of the network highly depends on distance range between devices and indoor environment. A reliable communication is two floor distance (15 m) or the communication can be lost or impossible to set.

As a general conclusion of the design and testing phases of the proposed alpha monitoring system, the study shows the performance of the system as a tool to monitor and optimize energy consumption. After one month of collecting data for the proposed system, by installing the system in student houses, we managed to define habits of the building users. This helped to obtain a profile for each room and the informing approach on the students lead us to validate the system's purpose to save energy. By using the monitoring system we managed to obtain savings between 8% and 21% and to make the first steps in creating a standard regarding the energy habits of the room user [3].

This result bring even more value to the scope of saving energy as the cost of using the system is one small investment for an indefinite period of time. It comes with a relatively simple structure and usage, having a user friendly interface and a low cost, while the energy savings on the long term can bring significant reduction on energy cost for the user and protection of the environment in terms of conservation of natural resources needed to produce energy.

7 Future Development

In a future development we plan to investigate the possibilities to extend the sensors used and the modularity aspects of the entire system. We expect that for the beta version to use batteries for the ending nodes and to implement a friendlier interface for the end user.

Another point of interest is to reduce as much as possible the device dimensions. In this way the new generation should have all the sensors in one single box. As described in the Fig. 10, we plan to integrate the entire Sensor in a layered module.

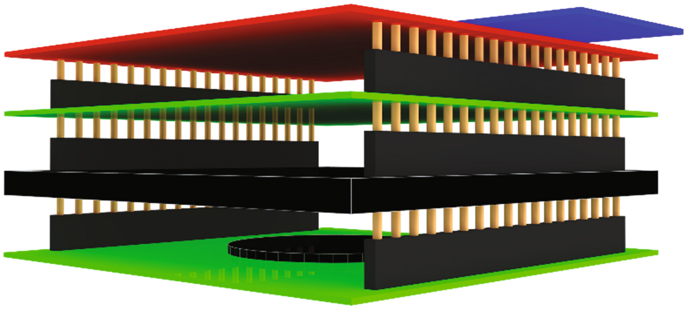


Fig. 10. Concept beta version-layered module

We are looking to explore the possibilities of using different technology like the PSoC Analog Coprocessor provided by Cypress as a layer of processing multiple sensors inputs. PSoC Analog Coprocessor integrates programmable analog blocks, including a new Universal Analog Block (UAB), which can be configured with GUI-based software components. By using this technology we aim to upgrade the ways we can design custom analog front ends for sensor interfaces.

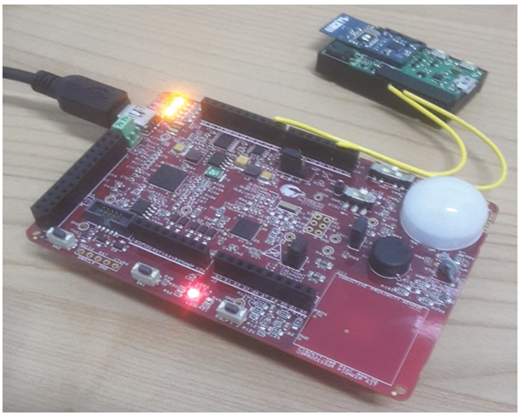


Fig. 11. CY8CKIT-048 PSoC from Cypress and CK-USB-04A from IQRF

More than that, due to our strong collaboration with Microrisc and to their complex structure of collecting, cloud storage and visual online platform, we intend to integrate into our system the IQRF transition technology. Till now the IQRF technology help us in our need of scaling the range of the system and on top of that, form our first test we were able to reduce to 20% the energy consumption of each node. As presented in Fig. 11 we started our test by using CY8CKIT-048 PSoC from Cypress and CK-USB-04A from IQRF.

Regarding the user approach we want to improve the web platform in order to give better access to each student. We also want to create a friendly way to send real time messages to students with possible actions. In order to protect the concept we will look for a solution to move all the processing algorithms from the hardware. Extra features will be also implemented in the same device, like CO2 and humidity sensors. This information will add even more value to our system providing quality of the air status in an indoor environment.

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