Final Report

Saxhof Foundation project title:

Integrated IoT-based Smart Building Modelling Tool (Phase I)

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Abstract

The current document provides a summary of project activities and achievements.

Chapter 1   Project description and objectives

Project description

This project is granted as the Phase 1 discovery project. The overall project proposes an IoT-based smart building modelling tool, which simulates the sensor network and data transmission system based on building information. The simulator aims to analyze the building architecture and materials to promote accurate design, minimize improper approximation and reduce costs in practice. This work is closely cooperated with DTU Byg. This phase1-discovery project will start the collaboration and initiate the project for the IoT based energy efficiency platform. For this project, we will 1) investigate the project specification and challenges, 2) initiate meetings with DTU Byg and address requirements, 3) setup outlines for a cross platform simulator to embrace both sensor network features and building construction and materials characteristics. Our primary goal is to realize the sensing and data collection system and identify the implementation related to building structure factors and building material factors.

Project objectives

This project acts as a discovery project in order to setup communications with researchers in DTU Byg department and relevant researchers in the research area of 'smart building and smart city'. A preliminary study will be started to investigate a cross- platform simulation that combines both wireless sensor network expertise and building/construction knowledge.

Project plan

Work process divided into two half-year phase in 2018 and 2019, respectively.

Period 1: 2018.05 – 2018.11	Period 2: 2018.12 – 2019.05
• Task 1a: Wireless sensor network based on LoraWAN technology. • Task 2a: wireless sensor network based on WiFi technology • Task 3a: Data visualization requirements and developments	• Task 1b: wireless signal conditions in relation to building materials and constructions; • Task 2b: simulation and emulation tools for WiFi technology • Task 3b: comparison of visualization tools and methods
• Meetings: a meeting on Oct 31st, 2018 for a workshop on Atea Digital Platform with Dag Stinus and Christian Hviid and other researchers from DTU	• Informal discussion with DTU Byg and DTU Compute on building materials and energy consumption modelling.

Chapter 2   Project activities and Results

Task 1: Wireless sensor network based on LoraWAN technology

The project is the implementation of a monitor system based on LoRaWAN protocol, which keeping track of the temperature sensors located in the DTU building Fotonik, for temperature value collection and sensor status monitoring. The main tasks of the project covered node connection, system building, data collection and visualization, application lunching.

In this project, in order to build the IoT-based energy efficiency platform, a web application was built to monitor a LoRaWAN connected temperature senor status. In this case, the sensors' location will be shown on a floor plan map, the temperature and other essential information about the nodes will also be illustrated in the application used for senor control and maintenance. Guides to collect data with a LoRaWAN enabled node, connect the node to TTN console, extract the data from TTN to own server, store them in SQLite and visualize them with D3 will be documented.
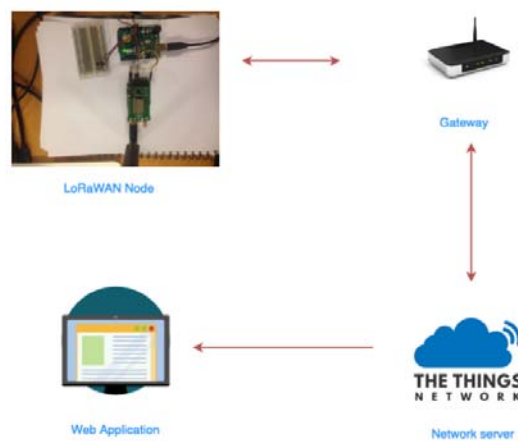
Step1: Using TMP36 Temperature sensors with Arduino

The essential data in this project, temperature, was detected by the TMP36 temperature sensor (Figure 1). The technology TMP36 used is based on the property of diodes to determine the temperature, as the voltage across a diode changes at a known rate while the temperature changes, so the TMP36 generate an analog signal as output which is linearly proportional to the temperature 2015b. This part will provide a tutorial about how to use TMP36 sensor with Arduino uno.
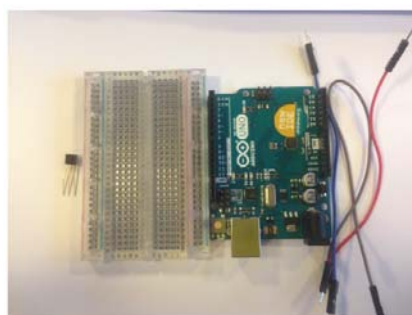

Figure 1: Temperature sensor prototype

Step 2: Node building: Connect RN2483 to the Arduino

The LoRaWAN module we used in the project is RN2483, the first LoRa module to pass LoRa Alliance Certification testing, ensuring a quickly and easily integration of end devices into the LoRaWAN network 2018a. The specific board embedded RN2483 is RN2483 LORA™TECHNOLOGYPICtail™/PICtail PLUS DAUGHTER BOARD 2015c, showed in Figure 2.
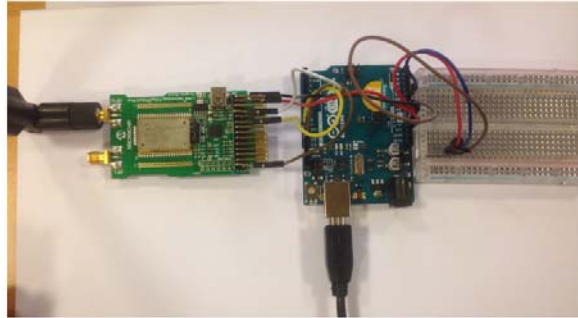

Figure 2: RN2483 LORA™TECHNOLOGYPICtail™/PICtail PLUS DAUGHTER BOARD

In the projrct, we chose RN2483 module as is a fullycertified 868 MHz module based on wireless LoRa technology, utilizes a unique spread spectrum modulation within the Sub-GHz band to enable long range, low power, and high network capacity features that LPWAN has. In this module, the embeded LoRaWAN protocol is Class A who enables seamless connectivity to any LoRaWAN compliant network infrastructure, whether public or privately deployed 2018a. All the futures the module has is user friendly, which shortens our development time and easy to maintain.

Step 3: TTN connection

The network operator we use The Things Network who plays the role to manage the received packets, perform security checks, schedule acknowledgments through the optimal gateway, and support integration. This IoT could service provider uses MQTT based device connectivity offers publish/subscribe semantics, makes it easier to program on the IoT device side. The Things Network is building a network for the Internet of Things by creating abundant data connectivity, it's an open source components enable the users to build a complete IoT solution using LoRaWAN standard. Which leads to a decentralized open and crowdsourced IoT data network, owned and operated by its users. 2017 As a stable and free using public community network who also get a guaranteed service level, maintenance and support, TTN is a great choice of network provider in our project.

Step 4: Floor plan visualization application

The goal of this section is to visualize the temperature data on the floor plan after the node was connected to the TTN. Firstly we use two different integration ways supporting by TTN to connect the device with the application for .JSON format file obtaining, then progress towards visualizing the sensor working status and temperature at a determined place on a floor plan graph using D3.js.
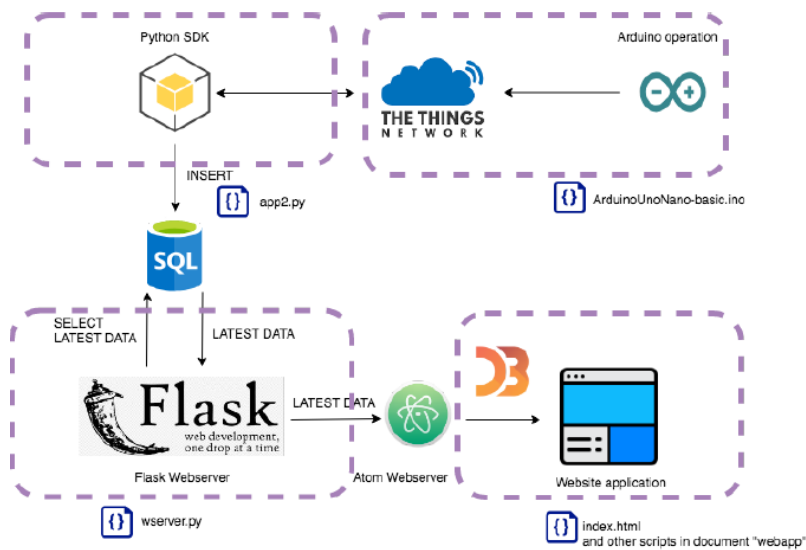
Figure 3. Visualization flowchart

1 Data storage integration

The data storage integration allows we to persist data in a database while a storage API allows we to query data and list devices for which data is stored by the integration 2018b, so in order to save the data and use it later, the storage integration is needed. The integration is simply click the buttons on the TTN.

2 HTTP integration

HTTP integration on TTN allows us to send all the payloads to a custom endpoint and downlink message is available over HTTP, it is a fast push based integration works with any HTTP endpoint. The steps are similar to the data storage integration, besides an unique identifier process ID should be entered since multiple HTTP integration could be added the same time: We use requestbin URL here, from the page we can collect all the requests, the body of the requests are the .JSON format which are convenient for later use in D3.js. In the raw body of the request, the appid and devid can be found for device identification, the payloadfields is the temperature we need for monitoring, also some useful metadata about the time gateway receive the message and the rssi(Received signal strength indicator) which indicate the quality of a received signal can the found in the request body.

3 SQLite data storage

It is necessary to make data visualized from devices to realize real-time monitoring, although the data had collected in .JSON format but it is used as local backup file instead of real-time data streaming. An essential transition method is need to cope with the real time visualization, as the D3.js is running on the client-side while the integration running on the server-side. The solutions be used in the project is building our own database for storage and real-time visualization.

4 D3.js visualization

D3.js, a library in JavaScript for interactive data visualizations, is used to achieve visible status of temperature in the buildings. D3.js can present data graphically by combining HTML, SVG and CSS which push it become the most popular library for visualization and website application building. In this section, the rooms equipped with the nodes marked with red dots on the floor plan. The sensor information will be shown as tooltips when the mouse hover the dots, including the device state, signal strength, and the temperature data.
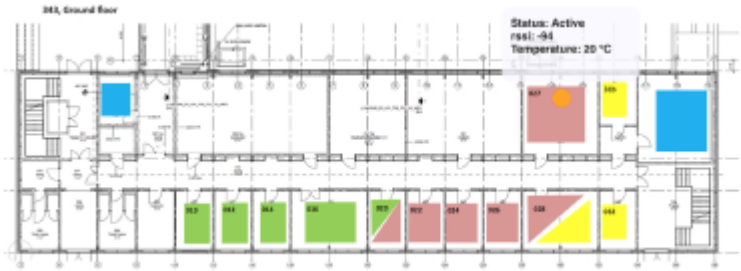
Figure 4: Floor plan sketch

The monitoring website demo could be shown locally by running the index.html file in the browser, the related code were attached in the appendix. The website application is mainly made up by three parts, the first one is a overview on whole Lyngby campus showing in Figure 5. Click the link on the dot where marked on the building 343 we put the LoRaWAN node in will lead to the part 2: building floor plan of Fotonik 343. Showing in Figure 6, if the users click the blue button "Floor plan" or "View", the floor map graph would un-stack and stack again. Such elegant animation was generated by the javascript script and css files for a better web visual interface.

Then click the floor we want to browse, here make second floor as example, a layout of second floor is generated which with a marker indicate the location of the LoRaWAN node on this floor seen Figure 7. Meanwhile when the cursor hover on the mark, the clue box pop out indicate the temperature and the signal strength in the room.

In order to control the temperature sensor in real time, if we click the dot on the map, the germ of something wonderful happened which could seen in Figure 8. There will be a line chart graph which updated in real time show in the right side window, every dot on the chart indicate a data we got from the temperature sensor. Also, a detailed information, temperature and the time, can be learned if the cursor hover on the dot. From the real-time line chart, we comprehend the trends of temperature in the room for the sensor monitoring. For a better user experience, the navigation bar on the top will bring the users to the part they want to dig for the useful information. Such as the very beginning which is campus overview, and the building 343 Fotonik floor plan. Also all the code for the web application could be found by clicking the Github link on the top.
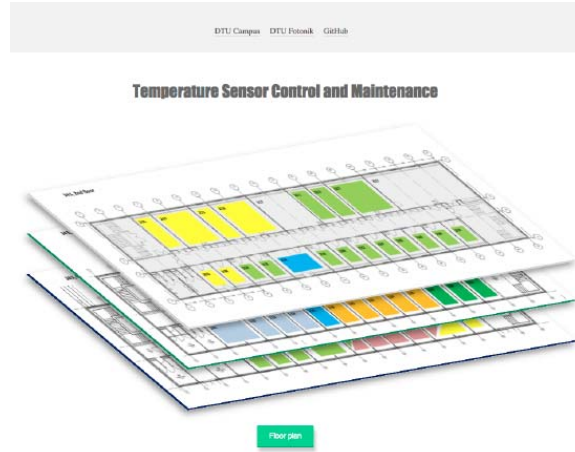
Figure 5: View on campus map
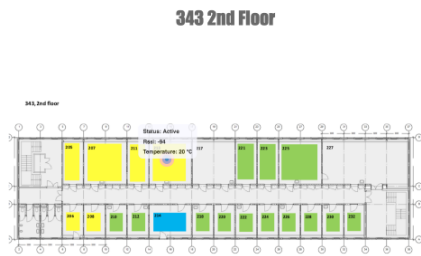

Figure 6: floor plan

Figure 7: 2nd floor plan

Figure 8: Real time monitor

Task 2: Testing and Results

The aim of this project is to focus on monitoring the temperature and humidity in the buildings 340 and 343 of the DTU Photonics Department. The idea is to install multiple temperature and humidity sensors at different, well chosen, locations throughout the two buildings. The strategic placement of sensors assures that the data collected is meaningful. To establish a connection between the temperature and humidity sensors distributed in the building, a LoRa gateway is set-up which sends the collected data to a web server, The Things Network (TTN).

As the goal of the project is to gain insight in the network communication performance in the buildings at DTU, information and conclusions about the improvement of the study environment can be drawn. In addition, energy savings can be achieved, as this IoT application can be connected to the indoor heating system. Thereby, the buildings will not be overheated and the wasting of energy is avoided. Figure 9 illustrates the overall setup of this IoT application.
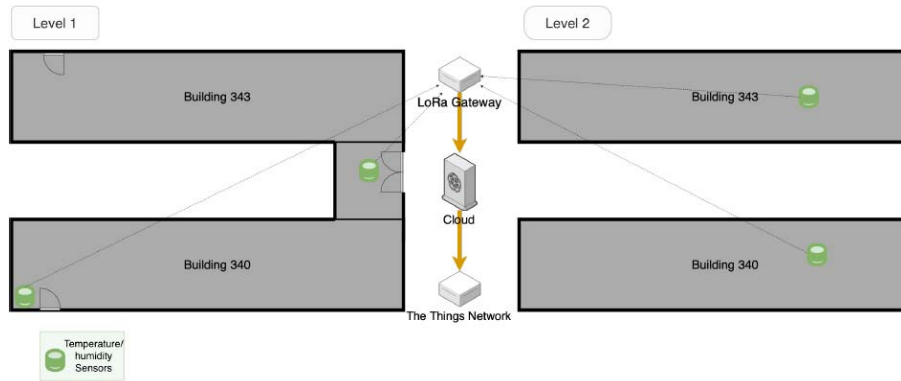
Figure 9: field test overview

The system set up is sketched in Figure 9. A rough floor plan of the two building indicates the locations of the endnodes. The setup consists of end nodes, featuring the temperature and humidity sensors, a LoRa gateway, sending the collected data,and the TTN, filtering and processing the data.

Measurements and test results

The devices were situated at DTU's Lyngby campus in building 343. The gateway was set on the second floor, connected to power and Internet. The node was operating at the ground floor in order to simulate real life usage as possible. The distance between the end-node and the gateway is approximate 58 meters calculated using Pythagoras theorem. Frequency used in the tests is 868.1 Mhz with 125 kHz bandwidth per channel. The SNR and RSSI tests were carried in in the following sequence: for each spreading factor (from 7 to 12), a payload of 20 and 40 bytes was sent 5 times. Airtime was calculated according to the formulas in the Specifications section. Battery life test results were obtained using the offcial LoRa ModemCalculator tool by Semtech. No specific tests were carried out for security and ease of integration. The two sections are based on the theoretical data and possibilities.

Link quality measurements

Multiple measurements were carried out in the process of evaluating the LoRaWAN indoor performance. Link quality subsection covers two important values which were measured indoors - RSSI and SNR. Both are measured at the end-device using the information gathered at the gateway. In order to obtain the results bandwidth of 125 kHz and coding rate of 4/5 was used when sending the packets. Figure 10 shows the measured RSSI (in blue) and the specified maximal theoretical values (in yellow) at different spreading factors. This test shows that the expected linear decrease of the sensitivity, as observed in the specified values, cannot be observed in the measured values. Comparison of the specified and measured results lead to a conclusion that the in-building test environment shows very good results across the 6 spreading factors. It shows the immunity against multiple signal disruptions such as multipath/fading, signal shadows, et cetera, in LoRa is high.
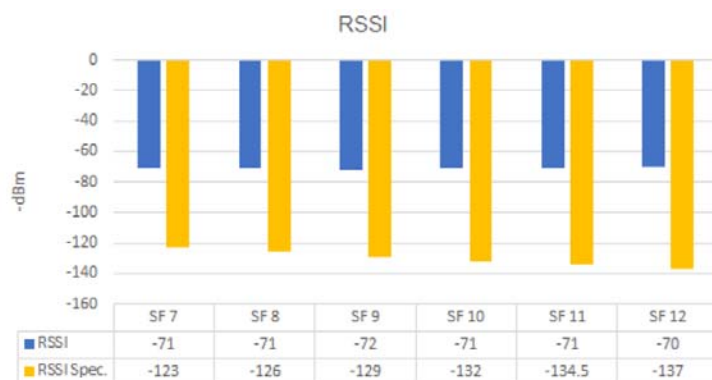
Figure 10 LoRaWAN RSSI measurements

As per LoRa modulation basics document, LoRa is capable of demodulating the signal below the noise floor, up to -20dB at SF 12. The link budget is also up to +15 dB in spreading factor 12 compared to +1 dB at SF 7. Figure 11 shows the different SNR (Signal-to-Noise Ratio) values at the different spreading factors. It can observed that at SF 9 the highest value - 12 is measured where the minimum across the other spreading factors is 9. The ability of LoRa to demodulate the signal below the noise floor and the given values in the table shows that the quality of the signal is above average in the measured conditions.
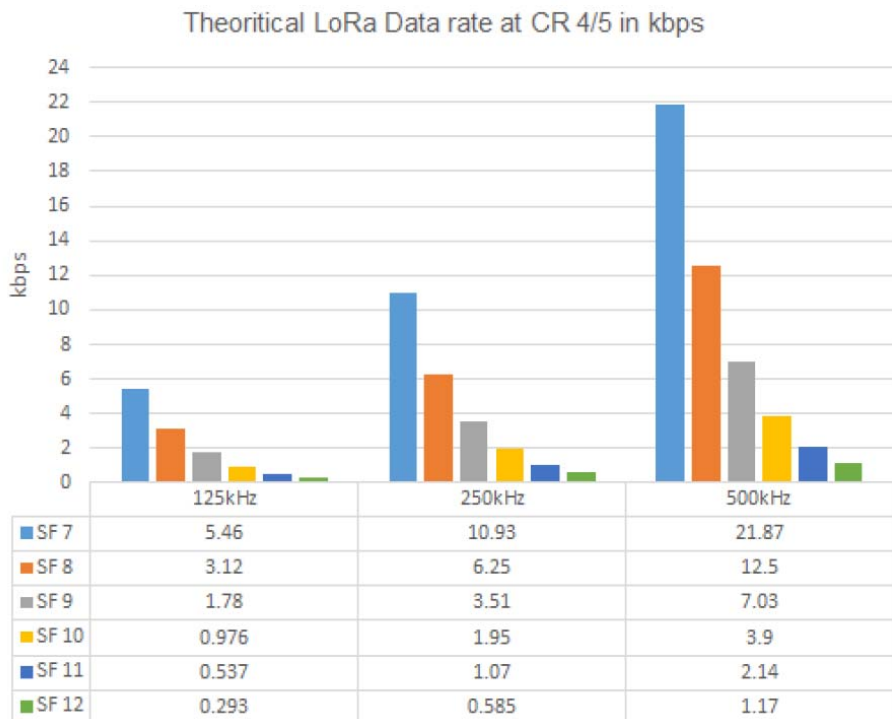

Figure 11 LoRaWan SNR measurements

Figure 12 shows a sample packet sent out from the LoRaWAN end node trough the LoRaWAN gateway to The Things Network back-end. It includes the payload data which contains the value from the photo-resistor. Also timestamp of the packet, spreading factor, bandwidth, coding rate, SNR, RSSI et cetera are included in the event data.

Figure 12 LoRaWAN frame payload TTN network

Throughput measurements

Throughput has a closer relation with the bandwidth and the spreading factor, as can be seen in Figure 13. It shows the theoretical data rate at the coding rate 4/5 and different spreading factors. As a rule of a thumb, the higher the spreading factor (SF) the lower the data-rate but the longest coverage and higher signal robustness. The linear progression in the data-rate values of at 125 kHz, 250 and 500 could be observed. As per design LoRa is low data rate technology which can

Theoritical LoRa Data rate at CR 4/5 in kbps

	125kHz	250kHz	500kHz
SF 7	5.46	10.93	21.87
SF 8	3.12	6.25	12.5
SF 9	1.78	3.51	7.03
SF 10	0.976	1.95	3.9
SF 11	0.537	1.07	2.14
SF 12	0.293	0.585	1.17

be observed in the tests.

Figure 13 Theoritial analysis of LoRaWAN data rate

Battery Life

Battery life is one of the important factors in systems utilizing sensor networks. As per design the sensor nodes should be as autonomous as possible. In this case, battery life of LoRaWAN end-node is estimated using calculations. The results are obtained using the official LoRa Modem calculator tool application simulating 1000 mAh battery. The tests were conducted using the maximal allowed antenna power output of 14dBm (further details can be found in Figure 14). All of the results below indicate only LoRa modem power consumption and do not include the microcontroller power needs for LoRaWAN. As mentioned earlier in Table 2.1, duty cycle is an important regulation that needs to be taken in consideration, in order to have a fully operational network. One of the ideas behind LPWAN's is capability of long time operation driven by a smaller-than-modern smart-phone battery.

Options	
Battery	1000 mAh, 3.3 V
BW	125 kHz
CR	4/5
Preamble	8 symbols
CRC	enabled
Header	enabled
Frequency	868.1 mHz
Power	14 dBm
Payload	20 bytes
Communication	Bi-directional

Figure 14 - LoRa options used in the tests

The real potential of LoRa/LoRaWAN can be observed in scenarios where data transmission is less frequent: every 5 or 10 minutes and short range (low SF). If we take, as an example, the middle section with messages being sent every 5 minutes, it can be noted that the lowest spreading factor performs really well - yielding more than 10 years of operation on single 1000 mAh battery. This is however not the case for SF 10, 11 and 12, where the results are not satisfactory. On the other hand, if the messaging is done once an hour, the LoRa technology shows incredible numbers around 6 years at SF12, and according to the official calculator, 116 years at SF 7 - over 10 times the shelf life of a Lithium battery [7]. Overall, the battery life remains good when transmissions occur with at least a 5-minutes break in between transmissions.

The table in Figure 15 shows aggregated data needed for transmission at different spreading factors based on 1 percent duty cycle restrictions. The battery life in days is shown at the bottom of the table for the different SF's taking in consideration the maximum allowed messages per day. The time between subsequent messages varies between the different spreading factors and is related with the Time on Air. For example at SF7, 20 byte payload is transferred for 71.94 milliseconds and 1 percent duty cycle yields 7.194 seconds between messages. It should be noted the results in battery life - around 3 months with 1000 mAh battery. This is significantly below the advertised "years" of operation found in the advertising papers. It should be mentioned that the size of the battery providing 10 years is not indicated in the papers as well. Even though the number of messages per hour decline with the increase of the spreading factor, the battery life is similar. This is caused by the proportional rising in transmission time with the rising of the spreading factor.

Transmission restrictions for 1 % duty cycle						
1 % Duty cycle	SF7	SF8	SF9	SF10	SF11	SF12
Time between subseq. Msg (s)	7.194	13.363	24.678	45.261	82.33	164.659
Max msg. per hour	500	269	146	80	44	22
Max msg. per day (24-hr)	12010	6466	3501	1909	1049	525
Battery life (days), max msg.	94.74	94.93	94.75	94.75	94.75	94.76

Figure 15 - Transmission Restrictions for 1 Percent Duty Cycle, Battery Life

The graph in Figure 16 illustrates the impact of the transmission periodicity on the battery life. Five categories are outlined based on the recurrence of sending messages: every 30, 60, 300, 600 and 6,000 seconds. Please note that the graph is limited to 10 years, as this is the top value for shelf-life of a battery. Self discharge is not included.
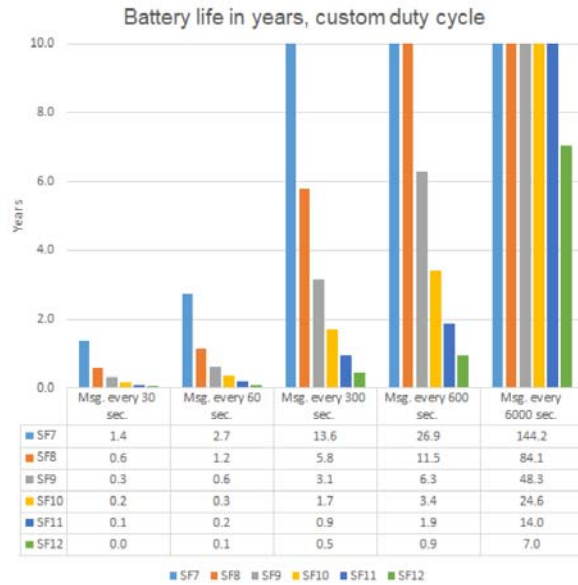

	Msg. every 30 sec.	Msg. every 60 sec.	Msg. every 300 sec.	Msg. every 600 sec.	Msg. every 6000 sec.
SF7	1.4	2.7	13.6	26.9	144.2
SF8	0.6	1.2	5.8	11.5	84.1
SF9	0.3	0.6	3.1	6.3	48.3
SF10	0.2	0.3	1.7	3.4	24.6
SF11	0.1	0.2	0.9	1.9	14.0
SF12	0.0	0.1	0.5	0.9	7.0

Figure 16 - Battery Life in Years, Custom Duty Cycle

Chapter 3 Summary

During this Phase-1 discovery project, there are a few students involved for implementing prototyping and setting up testbeds. The DTU buildings 343 and 340 have been used to examine and evaluate the relationship between signal transmission strength and building construction features.

Due to the lack of knowledge of building material and construction features, the results are shown with different transmission performance.

However, it is clearly shown differences in the new building (340) and the old building (343), when the same test platform is deployed.

Therefore, we will continue to look for consultant on the combination on the two fields. Java based simulation tool and Python based simulation tool have been investigated and used to receive theoretical results. It requires collaboration with DTU Byg in order to extend them with building construction information.