Internet of Things
Summer Semester 2025

Lab Exercise

Energy Lab

Prof. Dr. Anna Förster
Dr. Jens Dede
Dr. Asanga Udugama
Dr. Andreas Könsgen
Dr. Shadi Attarha

Prof. Dr. Andreas Willig
Dr. Gibson Kimutai
Thenuka Karunatilake
Saurabh Band
Jennifer Horstmann

Submission deadline: 28 May 2025, 12:00 midnight

You are required to work in groups of 3. The report to be written at the end should be developed by all members of the group together, but each member must upload a copy of the report, separately. The report should be in .pdf format and submitted using DoIT! at StudIP!.

Energy efficiency is a fundamental concern in the design of Internet of Things (IoT) systems, where devices are often battery-powered and deployed in locations where frequent maintenance or battery replacement is not feasible. These devices typically operate in low-duty-cycle patterns, performing sensing, processing, and communication intermittently while spending most of their time in energy-saving sleep modes. However, even short bursts of activity—especially wireless communication—can significantly impact battery life. To design energy-efficient systems, it is essential to model and analyze power consumption accurately. This lab exercise introduces you to the energy problem in IoT by guiding you through the development of theoretical and practical methods to estimate energy consumption for a development board operating in a periodic sensing scenario, with the goal of estimating device lifetime under different communication protocols such as WiFi and LoRa.

You are required to submit a report about the work, maximum 3 pages.
Details of the required content of the report can be found at the end of this document.

Caution!!!

Make sure the Antenna is connected to the board before powering up the device

Hardware and Setup

- Device: Development board (MoleNet)
- USB Power Meter: For measuring current and energy consumption
- Communication Modes: WiFi and LoRa
- Active for 30 seconds every 1 minutes

Basics and Introduction

In this exercise, we use the USB power meter to measure the power consumption of the development board. Refer to the *USB_meter_intro.pdf* document to learn how to use the USB-meter.

Task Description

The main goal of this exercise is to estimate the runtime for the given development board for the scenario given below. You are supposed to calculate the theoretical and practical values for the runtime. The complete exercise is divided into multiple Tasks which will help you to reach the final goal step by step. Following is the overview of Tasks:

1. Measure the practical charge consumption of the board, using USB meters, for the given scenario when the transmission takes place over LoRa and WiFi (Refer to Task 1).
2. Calculate the theoretical charge consumption of the board by building an energy model. Substitute the energy consumption for different components in the energy model, by obtaining values from different data-sheets (Refer to Task 2).
3. Use the practical and theoretical charge consumption to obtain two different values of runtime (practical and theoretical). Discuss the results (Refer to Task 3).

Please fill the provided solution sheet and submit it at the end of the lab.

Scenario

The given development board is to be deployed for monitoring in a remote field. The board is programmed to wake up every 1 minute. Every time it wakes up, it is active for 30 seconds. During the active time, the board reads the sensor values and transmits them over the wireless channel. For the remaining active time it checks for any incoming packets. The transmission is done over LoRa and WiFi, and the board runs on a 20000mAh battery.

Task 1 - Practical Charge Consumption (10 Points)

In this task, you need to get the practical charge consumption of the board when the board is behaving as mentioned in the scenario above. You need to obtain two values, when transmission takes place over i) LoRa and ii) WiFi. Write down the measured value in the provided solution sheet.

Hint: Charge Consumption calculated from the Power Consumption reading could be more accurate compared to the Charge Consumption observed on the USB meter.

i) LoRa

Use the provided code to get the desired behaviour of the board. Upload this code and use the USB meter to measure the charge consumption (mAh) of the board.

Don't forget to change the GROUP_ID in the code before uploading.

Take note of the following things before you start taking measurements.

- Reset the USB meter right before resetting the board so that the readings are not distorted
- As the board goes to sleep, it may disconnect from the IDE. In this case, do not try to connect to the board because this will stop the code execution. The code will still be running on the board.
- The code will perform 5 cycles i.e., it will run for 5 minutes.
- You can observe the onboard LEDs to ensure the board is still functioning. The power LED will be always on. The one above that will be on only when the device is in active mode, and the last LED will blink when a packet is transmitted.
- All three LEDS will be turned ON for 5 seconds once the execution of the code is complete. Immediately take note of the readings on the USB meter and capture a photo of the USB meter for the report.
- After this, you can connect to the board via IDE if needed.

NOTE: Keep in mind that the practical value of the charge consumption for the board is for 5 cycles (5 minutes).

ii) WiFi

Adapt the code to communicate over WiFi instead of LoRa. Ensure that rest of the code other than communication stays the same to replicate the same behaviour. Repeat the same procedure as LoRa for measurement.

Following are some details to implement WiFi communication:

- **SSID:** CN-Students
- **Password:** CnStudentsWiFiAccess123
- **IP Address:** 192.168.0.180
- **Port:** 9999
- Use **UDP** connection
- Send the following **payload:** as seen in equation 1. The first field is the Group-ID, followed by Packet-ID, temperature reading, pressure reading, and the IP address of the device. The sample payload is seen in equation 2

$$(group\_id,\ pkt\_id,\ temperature,\ pressure, ip\_addr) \tag{1}$$

$$(12,\ 25,\ 23.1,\ 101325, 192.168.0.108) \tag{2}$$

Task 2 - Theoretical Charge Consumption (10 Points)

The next step is to design an energy model for the development board to calculate the theoretical charge consumption over time for the given sensing scenario. Lets start for case i), where the communication takes place over LoRa.

i) LoRa

Data Collection

Typically, a good starting point is to estimate the current consumption of various components on board for different activities.

Complete the following Table 1 by finding the current values from the provided datasheets, and the duration of each phase from the provided scenario.

NOTE: The duration column consist of active time duration for each phase that will be used for calculation using Energy Model in following section. In the Duration column, put 0 for the Phases that will not be used in your energy model and the active time duration for the rest of the phases that are used for calculation.

Table 1: Theoretical Values

Comp.	Phase	Duration	Current
MCU	Lightsleep		
	Idle		
	Processing	30s	
BME280	Read	1s	2.8 μA
	Sleep		0.2 μA
SX1276 (LoRa)	Tx.	185 ms	26 mA
	Rx.		10.3 mA
	Sleep		0.2 μA

The following are some details you might need to complete the above table:

1. **MCU - Lightsleep**
   - VDD_SPI and Wi-Fi are powered down, and all GPIOs are high-impedance.
2. **MCU - Idle**
   - Work mode: modern-sleep
   - Freq: 160 MHz
   - Dual core in Idle state
   - Peripheral clocks are enabled
3. **MCU - Processing**
   - Work mode: modern-sleep
   - Freq: 160 MHz
   - Single core running 32-bit data access instructions, other core in idle state
   - Peripheral clocks are enabled

Energy Model

Now that you know the current consumption and duration of different phases of the sensor board (Table 1), we can use these details to design an equation to estimate the energy requirement of the board. In this exercise, we calculate the overall charge consumption of the board for a single cycle, which we refer to as the Energy requirement for the rest of the exercise. The charge is measured in mAh (milli-Ampere-hour) or Ah (Ampere-hour).

A simple approach for theoretical energy calculations is the additive model, where you calculate the energy requirements of different components onboard and add them together to get the overall energy requirement. The following is a basic equation (eq. 3) that can be used to calculate the charge consumption of the board.

$$C_{total} = C_{CPU} + C_{sensor} + C_{lora} \tag{3}$$

Expand equation 3 with the help of the phases of each component to obtain the final energy model.

Use the appropriate values to calculate the theoretical charge consumption of the board for one cycle.

Hint: Will the onboard indicator LED draw significant amount of current? Should it be included in the energy model?

ii) WiFi

Repeat all the steps for theoretical calculations, but this time consider the communication takes place over WiFi.

Data Collection

Complete the Table 2 by referring to the data sheets of different components. Use the same rules for filling the Duration column as mentioned above.

Energy Model

Adapt the energy model for WiFi and redo the calculations to obtain the theoretical charge consumption for WiFi communication for the given scenario.

Table 2: Theoretical Values

Comp.	Phase	Duration	Current
MCU	Lightsleep		
	Idle		
	Processing	30 s	
BME280	Read	1 s	2.8 μA
	Sleep		0.2 μA
IEEE 802.11bg (WiFi)	Tx.	1 s	285 mA
	Rx.		95 mA
	Sleep		-

Task 3 - Runtime Calculation (5 Points)

As mentioned in the scenario above, assume the board is powered with a 20000 mAh battery. How long will the board run? Calculate the theoretical and practical runtime for the board for the given scenario.

Fill the results in the Table 3 and discuss both approaches in the report

Table 3: Final Results

	LoRa		WiFi	
	Charge Consumption per cycle (mAh)	**Runtime (hours)**	**Charge Consumption per cycle (mAh)**	**Runtime (hours)**
Practical Value				
Theoretical Value				

The following are some suggestions for discussion. Feel free to use your own points for discussion.

- Comparison of theoretical and practical methods. Pros and Cons?
- Which communication is better for low power applications? Why?
- How can one optimize the provided code further to reduce power consumption?

Report

You need to submit a report, with a maximum of 3 pages. The content of this report should include the following information, as shown in the template.

Following is the template for the report:

- Report title: Energy Consumption in IoT Sensor Nodes
- Administrative information
  - Your name(s) and your matriculation number(s)
- Section: Results and Discussion:
  - Completed Tables 1, 2 and 3
  - Photos of USB meter measurements (for LoRa and WiFi)
  - Screenshot of the packet received by the server (only WiFi)
  - Steps for energy model design and final equation used for calculation (LoRa and WiFi)
  - Discussion of results
- Upload the code for WiFi communication as a ZIP file.