PRELIMINARY DESIGN REVIEW

PROJECT

Development of a multi sensor logger and a gateway using Bluetooth Low Energy (BLE) with PAwR capability.

TEAM MEMBERS

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ADVISOR

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Presentation Contents

PDR Objectives

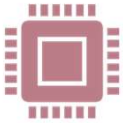
The primary objective of this project is to engineer a comprehensive system consisting of a battery-operated, low-power multi-sensor logger and a BLE/Wi-Fi gateway.

This integrated system will facilitate communication with a minimum of three sensor loggers, each collecting data from various environmental parameters. The core focus lies in implementing Bluetooth Low Energy (BLE) technology, enhanced with PAwR capability (Periodic Advertisement with Response), to ensure the most power-efficient data transfer possible.

The multi-sensor logger units are designed for minimal power consumption, allowing extended operation on battery power. Through the gateway, which serves as a central hub, data collected from the sensor loggers will be efficiently transmitted using BLE, with the PAwR capability enabling extended communication range when needed.

Additionally, the gateway supports Wi-Fi connectivity for broader data transfer to external servers or the cloud. By achieving these objectives, the system will provide a robust, scalable, and power-efficient solution for collecting and transmitting sensor data in various environments.

Requirements



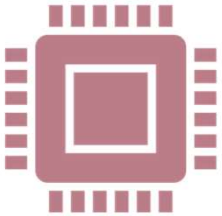
PAwR Protocol Integration: The system shall integrate the PawR protocol to enable efficient communication between sensor loggers and the gateway without the need for establishing a connection.

Data Low-Power Operation: The sensor loggers and the gateway have to operate efficiently on battery power, optimizing power consumption to extend battery life

Multi-Sensor Data Acquisition: The sensor loggers should be capable of measuring temperature, humidity, and accelerometer data at configurable sampling intervals and logging the data in their memory

Gateway Functionality: The gateway shall synchronize with multiple sensor loggers, configure their settings, retrieve current measurements, download logs, and publish data via WIFI using MQTT

User Interface Development: A mobile/desktop application, namely EFR connect will be used to set up the sensor loggers and the gateway to show the data collected

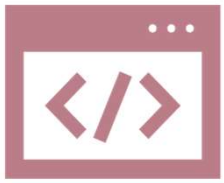


PAwR Protocol Integration

Research and understanding the principles of the PAwR protocol. Design and implement firmware for both the sensor logger and the gateway to develop PAwR for configuration, data transmission, and firmware upgrades. Test the integration to ensure seamless communication.

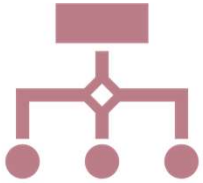
Low-Power Operation

Integrate power-saving algorithms and mechanisms in firmware for both the sensor loggers and the gateway. Optimize the usage of Bluetooth and WiFi functionalities to minimize power consumption during operation. Conduct thorough testing to measure power consumption and calculate battery life.



Multi-Sensor Data Acquisition.

Design and implement firmware for the sensor loggers to accurately measure temperature, humidity, and accelerometer data. Develop algorithms to log the data in memory and configure sampling intervals. Test the sensor loggers to ensure accurate data acquisition and logging..



Gateway Functionality.

Develop and implement firmware for the gateway to communicate with multiple sensor loggers. Create tools for configuring settings, retrieving measurements, and downloading logs from sensor loggers. Implement MQTT communication to publish data over WiFi. Conduct extensive testing to ensure gateway functionality.

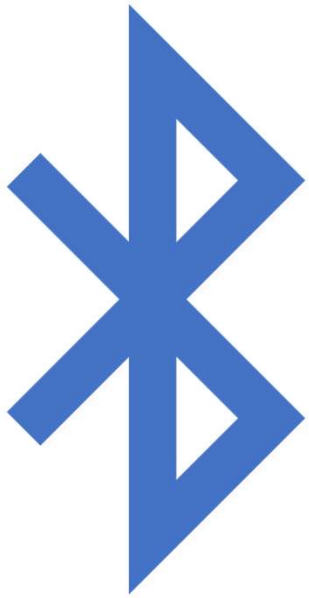
User Interface Development.

Develop a user-friendly interface for the mobile/desktop application to interact with the sensor loggers and the gateway. Implement functionalities for configuration, data visualization, and interaction with the devices. Test the application for usability and functionality across different platforms.

Developing with Silicon Labs

Bluetooth Low Energy (BLE)

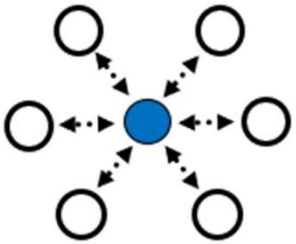
- Bluetooth is a wireless technology designed for data transfer and exchange over short distances.
- Bluetooth makes use of the Industrial, Scientific and Medical (ISM) band at 2.4 GHz.
- Traditional Bluetooth technology is optimized for sending a steady stream of high quality data in a power-efficient way.
- **BLE** allows for short bursts of long-range radio connections, making it ideal for long battery life without high throughput streaming data.



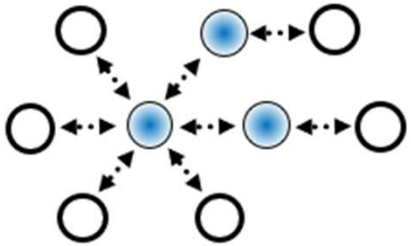
What does a BLE system look like?

Beacon

Point to Point



Star

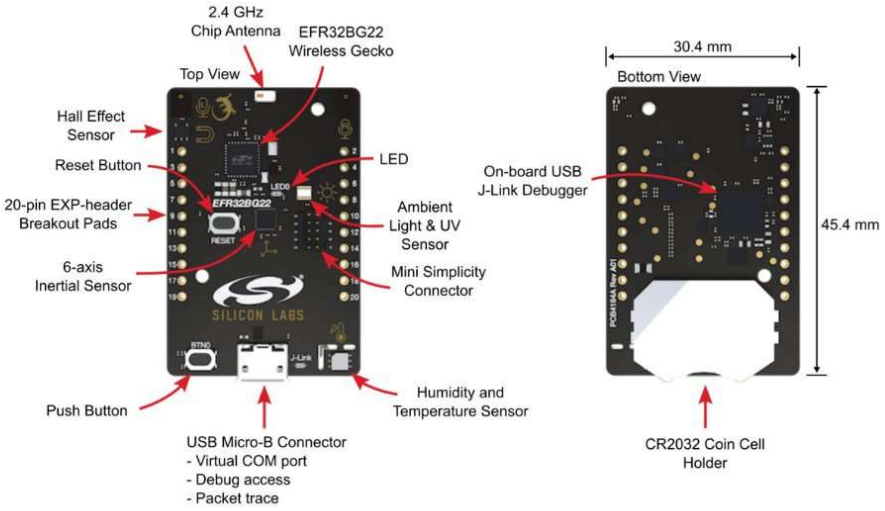


LE dual topology

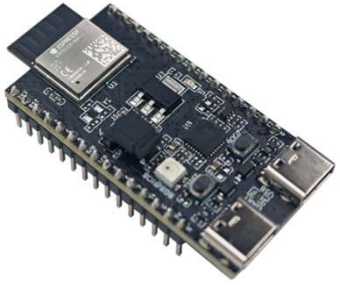
Bluetooth®

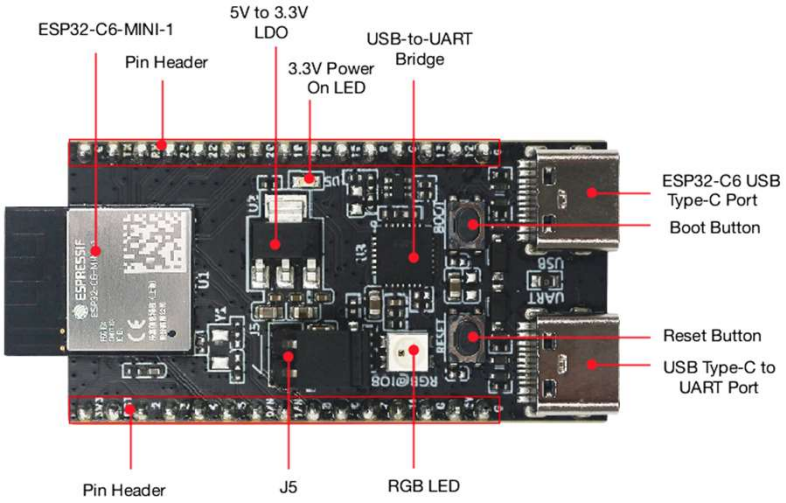
System Overview:

SiLabs EFR32BG22 Thunderboard

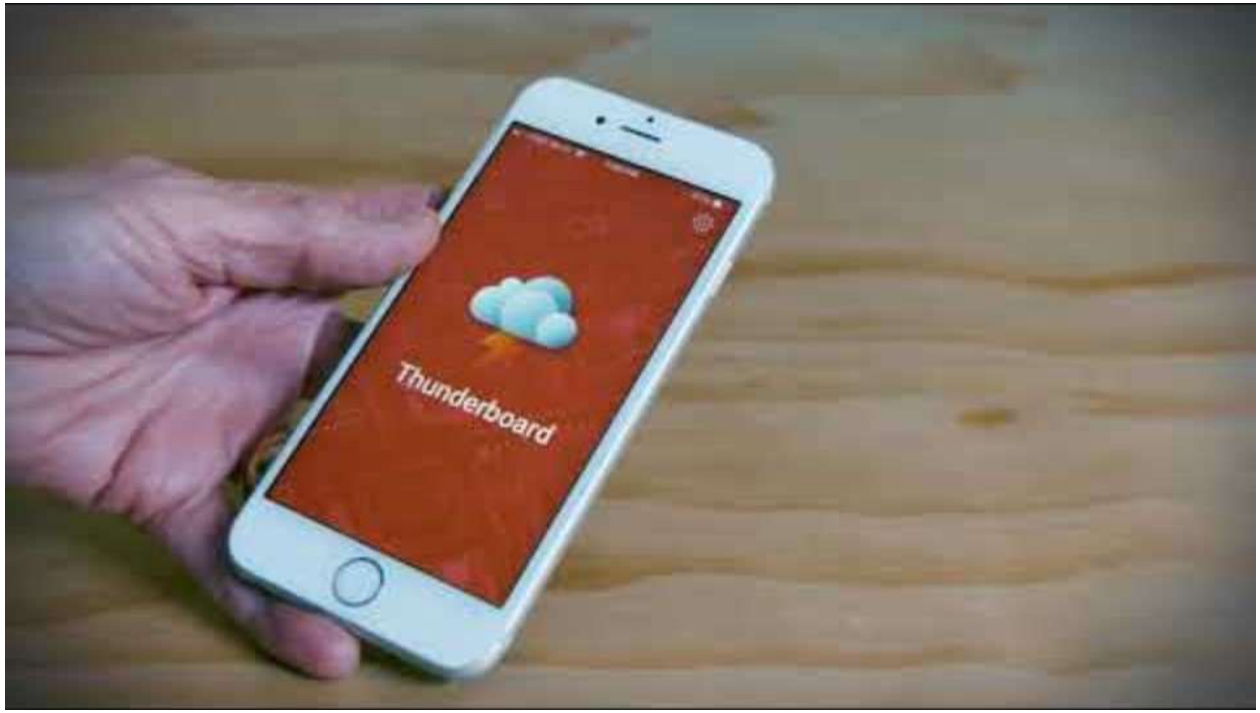


Esspressif ESP32





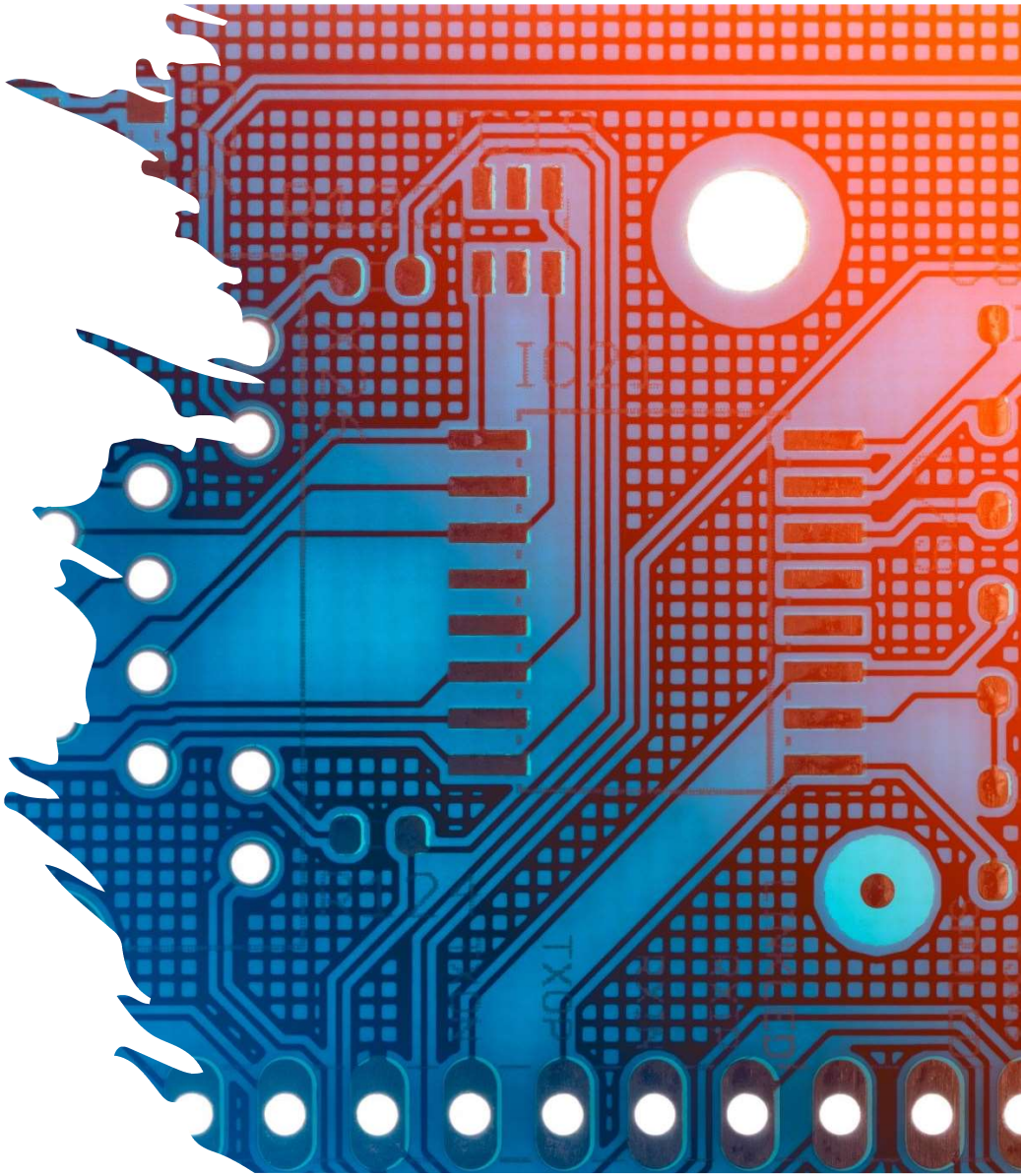
SiLabs Thunderboard



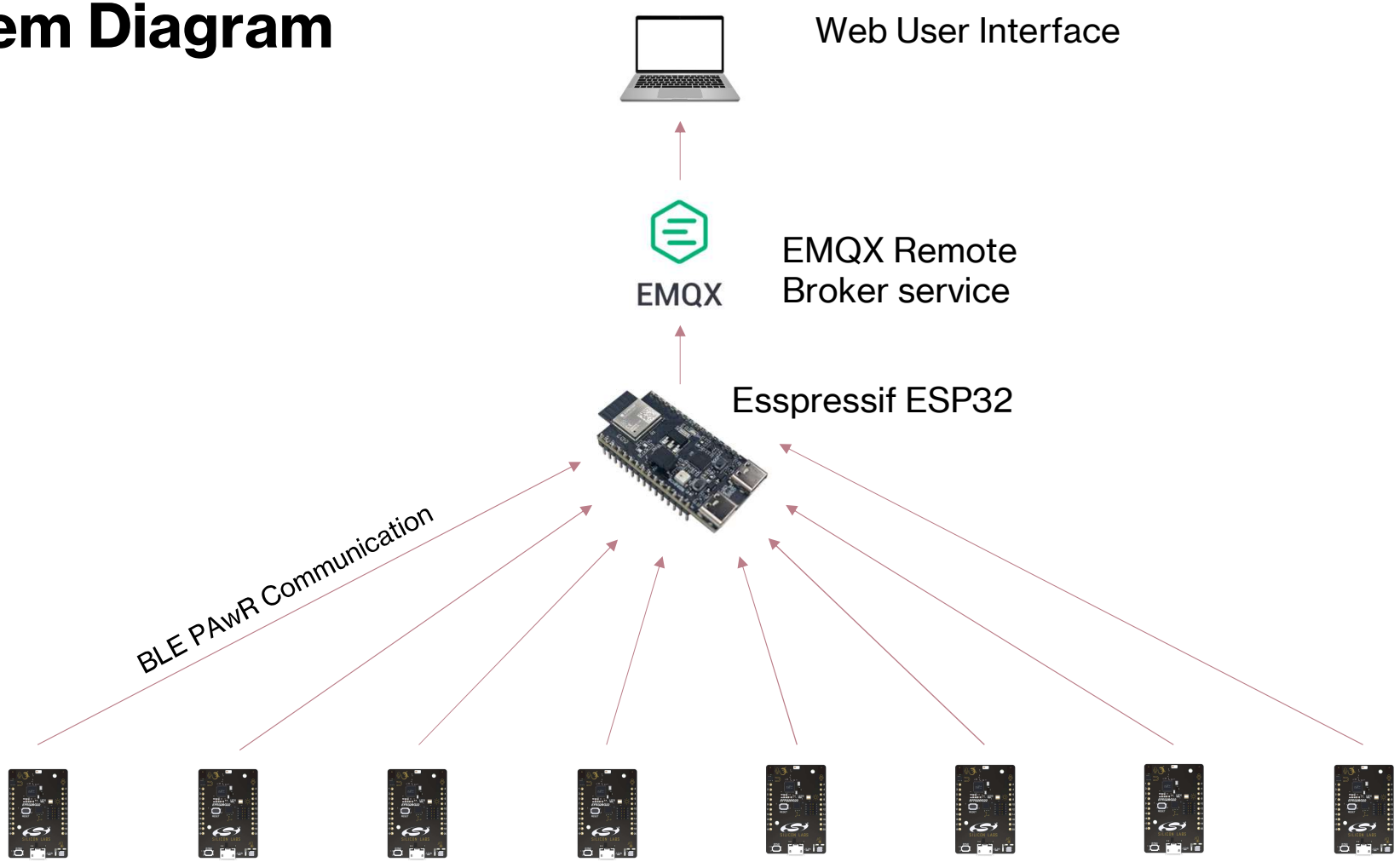
What is it?

ESP32-C6 is a system on a chip that integrates the following features:

- Wi-Fi 6 (2.4 GHz band)
- Bluetooth Low Energy
- 802.15.4 Thread/Zigbee
- High performance 32-bit RISC-V single-core processor
- Multiple peripherals
- Built-in security hardware



System Diagram



Sequence Diagram

1

a. Sensor Input: The Bluetooth mesh boards take input from embedded sensors (Temp, humidity, noise, light).

b. Sensor data is stored on board memory until advertisement signal is received.

2

a. Upon receiving the correct serial communication the Bluetooth sensor board will send data packets over secure network to the gateway.

b. Periodic Advertisements with Response (PAwR) protocol will ensure fluid sensor data transfer.

3

a. The ESP32 gateway will advertise data packets over the network to establish the mesh Bluetooth sensor network.

b. During the receiving interval the gateway will receive the data packets from the Bluetooth sensor boards and categorize the data before sending it to the MQTT broker.

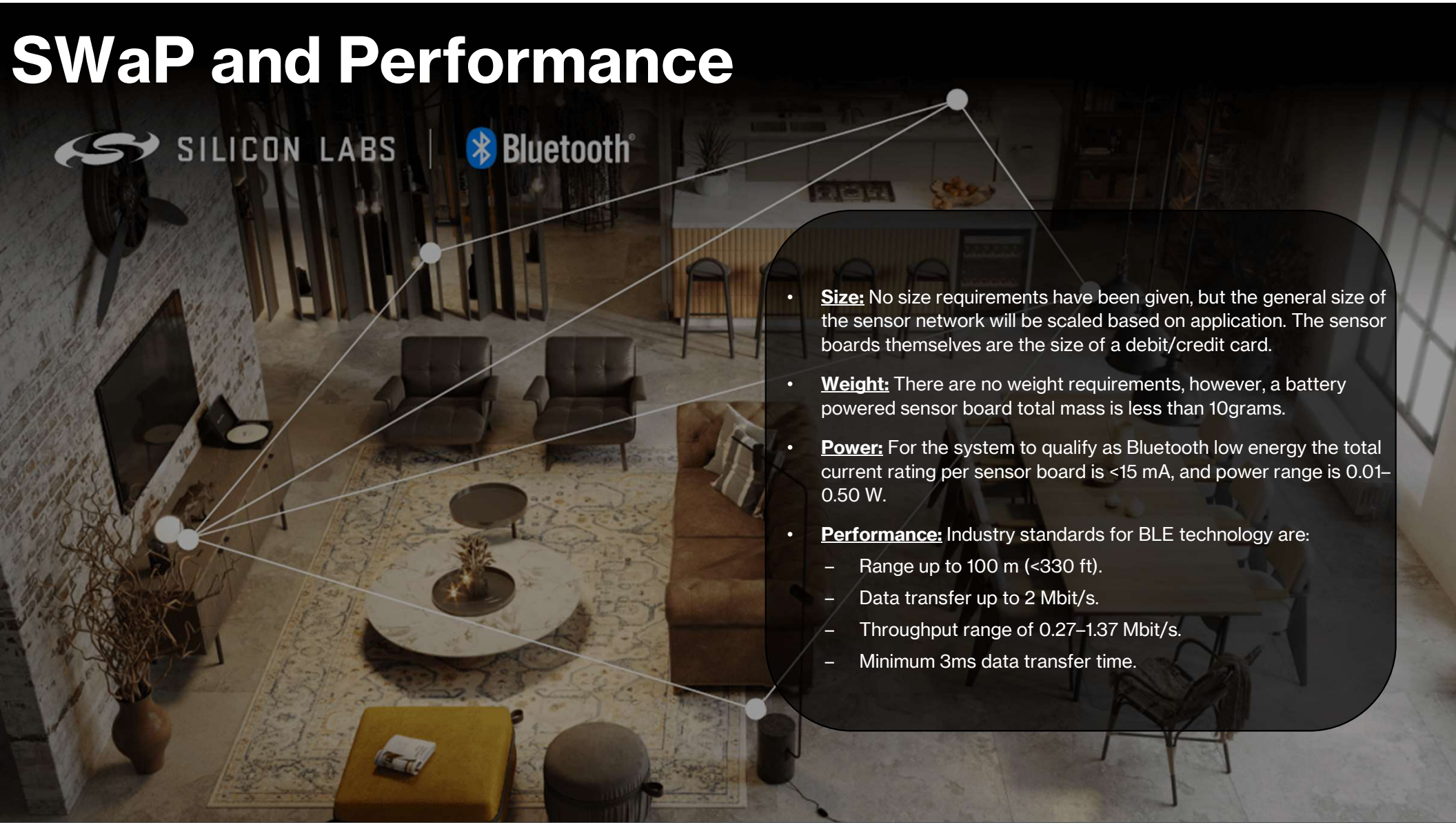
4

a. The remote MQTT broker service EMQX will facilitate the transfer of the collected and sorted data from the gateway to a web server for storage.

5

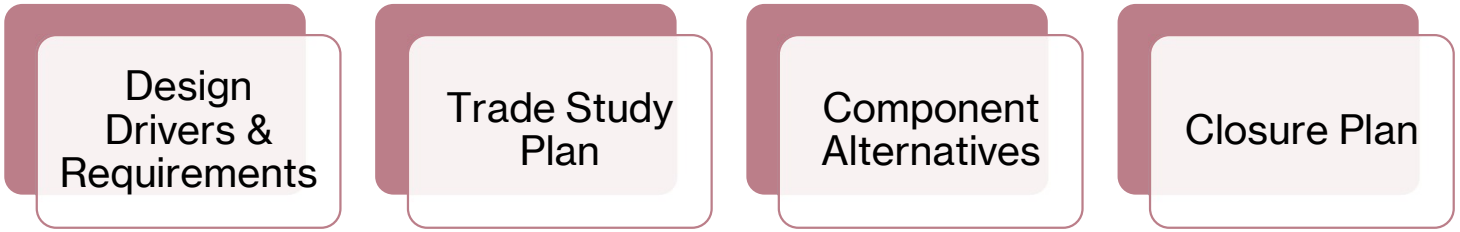
a. The web user interface will receive the data transmitted via the MQTT broker service and store it in a formatted and categorized spreadsheet for user access.

SWaP and Performance



- **Size:** No size requirements have been given, but the general size of the sensor network will be scaled based on application. The sensor boards themselves are the size of a debit/credit card.
- **Weight:** There are no weight requirements, however, a battery powered sensor board total mass is less than 10grams.
- **Power:** For the system to qualify as Bluetooth low energy the total current rating per sensor board is <15 mA, and power range is 0.01–0.50 W.
- **Performance:** Industry standards for BLE technology are:
  - Range up to 100 m (<330 ft).
  - Data transfer up to 2 Mbit/s.
  - Throughput range of 0.27–1.37 Mbit/s.
  - Minimum 3ms data transfer time.

Technical Trade Study Plan



Design Drivers & Requirements

Key factors influencing design

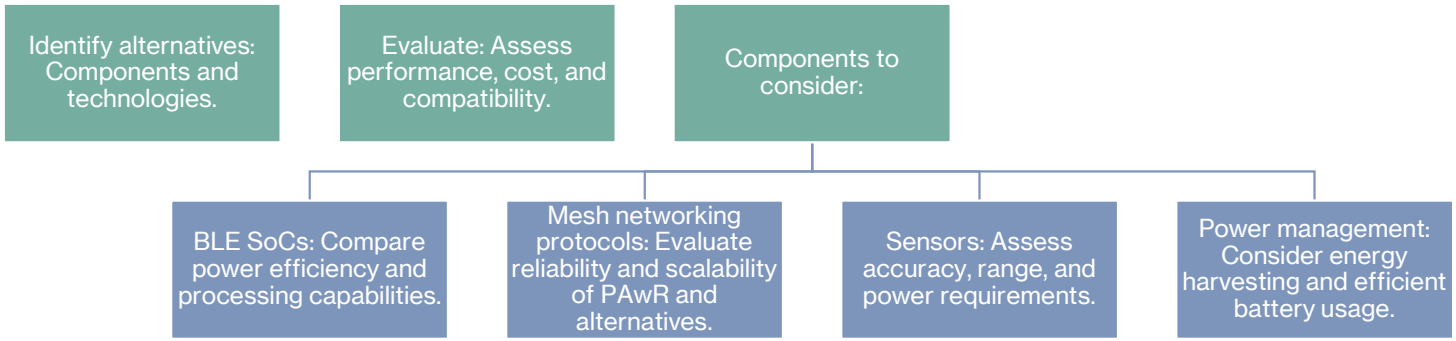
Power consumption: Minimize to extend battery life.

Scalability: Ensure network can accommodate growing number of nodes.

Latency: Minimize delay for real-time data transmission.

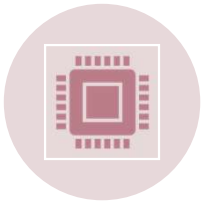
Security: Implement robust encryption and authentication mechanisms.

Trade Study Plan



Component Alternatives

Summary of alternative components and technologies



BLE SoCs: Nordic Semiconductor nRF52 series, Texas Instruments CC26xx series.

Mesh networking protocols: PAwR, Zigbee, Thread.

Sensors: Bosch BME280 for environmental sensing, TI TMP116 for temperature sensing.

Power management: Maxim Integrated MAX17222 for low-power voltage regulation.

Closure Plan

Studies that remain open or unresolved after the trade study.

Timeline for further investigation: Conduct thorough testing and validation within 3 months.

Final decision criteria:

Select components based on performance, cost, and compatibility.

Contingency plans:

Identify backup options in case selected components face challenges during implementation.

Project Test Requirements

Requirement #	Function	Requirement	Test Method	Date Reviewed
1	Development Environment	Ensure Development Environment Readiness	Inspection	TBD
2	Network Internals and ESP SDK	Testing Wi-Fi Access Point Mode, Connection and MQTT Communication	Demonstration	TBD
3	Implementation without PAwR	Configuring Device Parameters, Testing Logging Mechanism and verifying Status Service Functionality	Test	TBD
4	PAwR Implementation	Testing PAwR Functionality and Firmware Upgrade	Test	TBD
5	System Integration and Testing	Comprehensive System Integration Testing, Code Cleanup and Bug Fixes	Test	TBD

Risk Analysis and Mitigation

TOP TWO RISKS:

1. **Programmatic Risks**
   - Packet Loss due to frequency band interference
   - Range limitations
   - Security Vulnerabilities

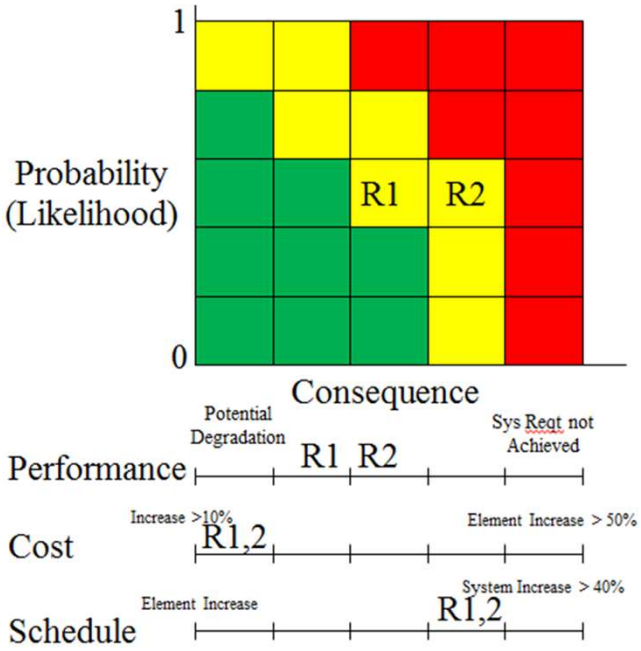
2. **Implementation Risks**
   - Compatibility

Mitigation – Programmatic

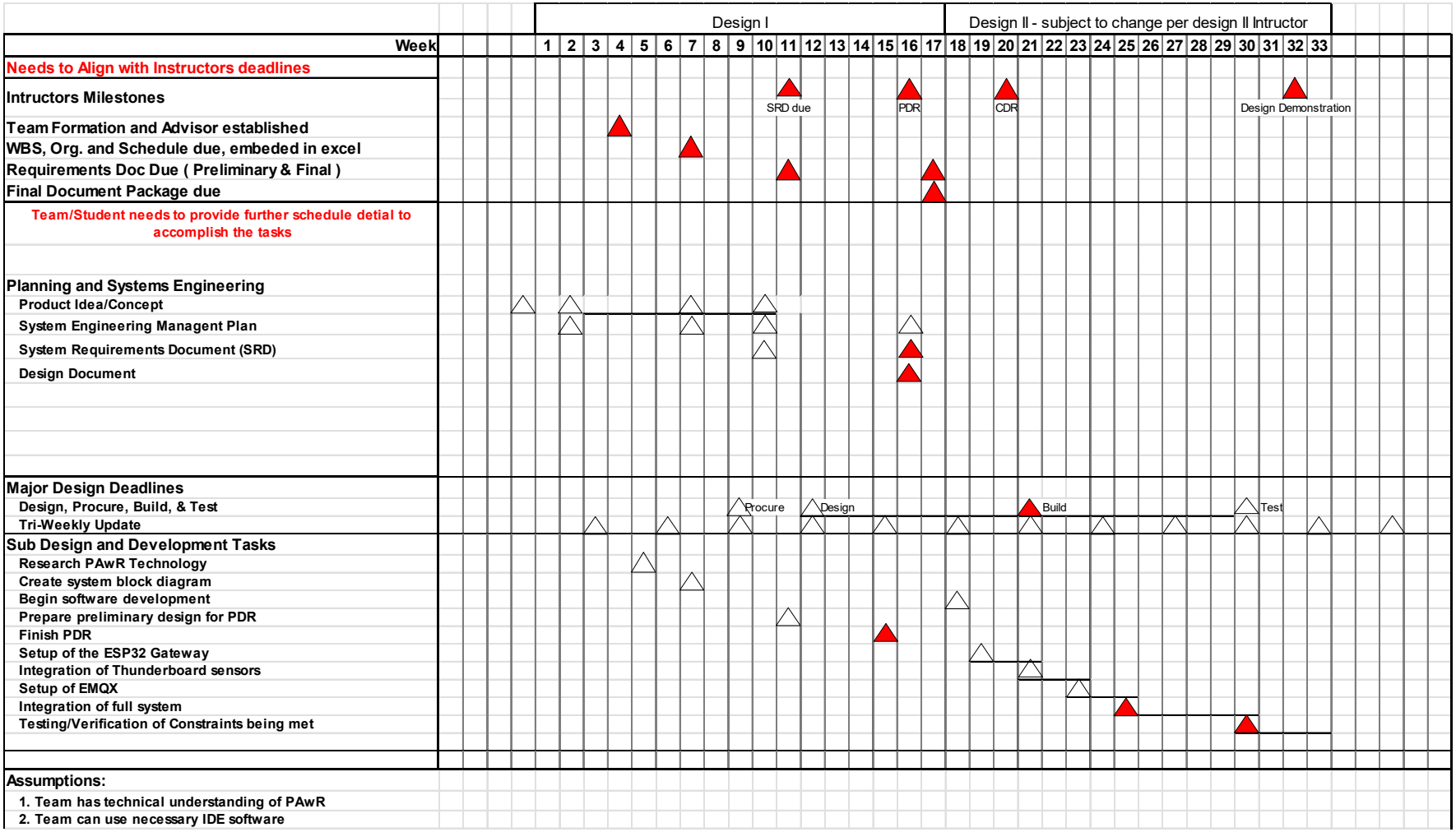
- Conduct validation testing to ensure proper synchronization, timing accuracy, and reliability.
- Implement signal strength-based proximity detection to limit communication to nearby devices and reduce the risk of security breaches.

Mitigation – Implementation

- Provide alternative mechanisms or communication methods for devices that do not support PAwR.



Project Schedule



Bill of Materials

Index	Component Name	Short description	function, how it is used in your system	Quantity	Cost	Reference or links to websites
1	ESP32 Dev Kit	For the system gateway	main access point for the system	2	$8	https://www.espressif.com/en/products/socs/esp32
2	Silab BG22 Dev Kit	for the sensors	individual sensor loggers	8	$45	https://www.silabs.com/wireless/bluetooth?tab=kits#dev
3	Cmake	IDE	software used to design the system	x	FREE	https://cmake.org/
4	conan.io	web based dev software	used to manage external dependancies	x	FREE	https://conan.io/
5	protobuf	communictaion protocol software	used to manage communication protocols	x	FREE	https://protobuf.dev/
6	Simplicity Studio	SiLabs IDE	main IDE workspace for the BG22 kits	x	FREE	https://www.silabs.com/developers/simplicity-studio
7	EMQX	MQTT remote broker service	used to connect ESP32 to web interface	X	FREE	

Note: Zthru supplied and paid for all development hardware, and all SDK's were free and open source.

Total = $376 USD

Review Action Register

#	Date Created	Originator	Description	Assignee	Original Due Date	Status	Updated Due Date	Status and Closure Comments	Aging
1	1/25/24	Dillon	Create Teams group + invite members	Dillon	1/25/24	Closed	1/25/24	Teams group is created and members + faculty invited	0
2	1/28/24		Meet Faculty advisor	Dillon	1/29/24	Closed	1/29/24	advisor/team availability does not align	0
3	2/4/24	Yowhannes	Read Deliverable from industry sponsor	Team	2/9/24	Closed	2/9/24	Everyone read the initial outline	0
4	2/9/24	Tatyana	WBS Development	Dillon	2/19/24	Closed	2/19/24	Dillon and Yowhannes completed this	0
5	2/11/24	Ngan	Research PAwR Technology	Team	2/19/2024	Closed	2/26/2024	Awaiting Meeting with Engineer to discuss PAwR	-7
6	2/19/24	Dillon	Meet with Industry Engineer	Team	2/26/24	Closed	2/26/24	Meeting scheduled	0
7	2/26/24		Review project outline		3/4/24	Closed	3/4/24	Document sent on 3/1/24	0
8	2/26/24		Install Simplicity Studio		3/4/24	Closed	3/4/24	Install IDE and connect BLE devices	0
9	3/4/24	Ngan	Use EFR app to test Thunderboards	Team	3/4/24	Closed	3/4/24	Entire team tested the EFR connection	0
10	3/4/24	Tatyana	Begin Project Packet 1	Ngan	3/11/24	Closed	3/11/24	Whole Team to begin packet 1	0
11	3/4/24		Begin Project Packet 1	Yowhannes	3/11/24	Closed	3/11/24		0
12	3/4/24		Begin Project Packet 1	Tatyana	3/11/24	Closed	3/11/24		0
13	3/4/24		Begin Project Packet 1	Dillon	3/11/24	Closed	3/11/24		0
14	3/10/24	Dillon	Begin working with wifi card	Tatyana	3/18/24	Closed	3/18/24	Dillon and Tatyana will handle the ESP32	0
15	3/10/24		Begin working with wifi card	Dillon	3/18/24	Closed	3/18/24		0
16	3/10/24		Begin working with BLE sensor card	Yowhannes	3/18/24	Closed	3/18/24		0
17	3/10/24		Begin working with BLE sensor card	Ngan	3/18/24	Closed	3/30/24	There are issues with install package in	-12
18	3/17/24	Dillon	Finish Prelim SRD	Team	3/18/24	Closed	3/18/24	Dillon started the document and shared	0
19	3/17/24	Tatyana	Begin Project Package 2	Ngan	3/25/24	Closed	3/25/24	Package 2 is to research a list of important tech topics	0
20	3/17/24		Begin Project Package 2	Yowhannes	3/25/24	Closed	3/25/24		0
21	3/17/24		Begin Project Package 2	Tatyana	3/25/24	Closed	3/25/24		0
22	3/17/24		Begin Project Package 2	Dillon	3/25/24	Closed	3/25/24		0
23	3/24/24	Ngan	Research for Device Safety	Ngan	3/30/24	Closed	3/30/24		0
24	3/24/24		Begin working with BLE sensor card		3/30/24	Closed	3/30/24		0
25	3/24/24		Begin Project Packet 1		3/30/24	Closed	3/30/24		0
26	3/24/24	Yowhannes	Begin working with BLE sensor card	Yowhannes	3/30/24	Closed	3/30/24		0
27	3/24/24		Finish section 3 SRD	Team	3/30/24	Closed	3/30/24		0
28	3/30/24	Dillon	Begin Package 3	Dillon	4/7/2024	Closed	4/7/2024	Package 3 is the development of the ESP32 wifi gateway	0
29	3/30/24		Begin Package 3	Yowhannes	4/7/2024	Open	4/7/2024		0
30	3/30/24		Begin Package 3	Ngan	4/7/2024	Open	4/7/2024		0
31	3/30/24		Begin Package 3	Tatyana	4/7/2024	Open	4/7/2024		0
32	3/30/24	Tatyana	Begin PDR Presentation	Dillon	3/30/2024	Closed	3/30/2024	Dillon has created the presentation and filled in most of the slides, only some minor changes remain before completion.	0
33	3/30/24	Dillon	Help finish the PDR Presentation	Team	4/15/2024	Open	4/15/24		0
34	3/30/24		PDR: Risk	Tatyana	4/15/2024	Open	4/8/24	Identify project risk and mitigation methods	7
35	3/30/24		PDR: Overview/Mission	Ngan	4/15/2024	Closed	4/8/24	Objective, requirements, schedule etc.	7
36	3/30/24		PDR: SRR	Yowhannes	4/15/2024	Closed	4/8/24	Make sure that the project requirements are clearly stated in PDR	7
37	3/30/24		PDR: Integration and Test	Dillon	4/15/2024	Closed	4/8/24	Are the planned testing methods adequate?	7
38	3/30/24		PDR: Determine Speaking Order	Team	4/15/2024	Open	4/14/24	Team breakdown of who presents what.	1
39	3/30/24		PDR: Record Feedback	Tatyana	4/15/2024	Open	4/15/24	After we present the PDR slides, record class feedback.	0
40	4/8/24	Dillon	Finish and sumbit PDR	Team	4/15/2024	Open	4/15/24		0

Note: Picture taken prior to completion of PDR presentation

References:

1. https://www.silabs.com/documents/public/data-sheets/efr32bg22-datasheet.pdf
2. https://en.wikipedia.org/wiki/Bluetooth_Low_Energy
3. https://www.youtube.com/watch?v=itybLuMc8gw
4. https://docs.silabs.com/bluetooth/latest/bluetooth-start/
5. https://www.silabs.com/wireless/technology
6. https://docs.silabs.com/bluetooth/latest/bluetooth-fundamentals-overview/
7. https://www.silabs.com/documents/public/user-guides/ug103-14-fundamentals-ble.pdf
8. https://docs.silabs.com/bluetooth/7.0.1/bluetooth-fundamentals-advertising-scanning/
9. https://docs.silabs.com/bluetooth/7.0.1/bluetooth-fundamentals-connections
10. https://docs.silabs.com/bluetooth/7.0.1/bluetooth-gatt/
11. https://docs.silabs.com/bluetooth/7.0.1/bluetooth-fundamentals-system-performance
12. https://docs.espressif.com/projects/espressif-esp-dev-kits/en/latest/esp32c6/esp32-c6-devkitm-1/user_guide.html
13. https://data.energizer.com/pdfs/cr2032.pdf
14. https://eu.mouser.com/datasheet/2/368/efr32bg22_datasheet-1830163.pdf
15. https://eu.mouser.com/new/silicon-labs/silicon-labs-efr32bg22/#:~:text=These%20devices%20deliver%20industry%2Dleading,for%20up%20to%20ten%20years.