CS 481

Park-IT-CdA Design Report

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# Executive Summary

Too much time and effort are spent by those looking for a place to park in one or more garages in downtown Coeur d’ Alene. Commuters would benefit greatly from a system that indicates whether there are spaces available for parking within a parking garage. The Garage Sensor System (GSS) will allow people to find open parking spaces, and hopefully provide this information before they enter the garage. The Garage Sensor Units (GSU) will be placed above parking stalls to indicate the status via LEDs; a green light means there is an open stall, where a red means the stall is currently occupied by another vehicle. This is not the complete functionality of the system, but rather a level of abstraction for the consumer; the data that is measured/collected, will be distributed from device to device via a wireless network, then sent through a gateway where it will be received at The Den as a means of data collection for possible further research.

Due to COVID-19, the original plan was unable to be completed. The contingency plan implemented the sensing in one of the team member’s garages and a limited wireless network. The data was then successfully received over the internet at another member’s house and the simulation provided real time updating of the garage.

# Background

* Describe sponsor motivation for the work
* Identify the need/opportunity associated with this project
* Summarize benefits to different stakeholders

# Problem Definition

Park-IT-CdA is a parking garage monitoring system located in Coeur d’Alene, Idaho at the parking garage between 3rd and 4th Avenue and along Coeur d’Alene Avenue. It is capable of detecting when a car is parked in a stall and will relay this information to a server which will monitor the parking garage’s statistics such as: time from entering the garage to finding a stall, average time a stall is occupied, average number of stalls used and the current state of all stalls.

The GSS is comprised of 5 Garage Sensor Units (GSU). The GSUs will decide among themselves which is to be the Garage Sensor Master (GSM).

The deliverables are to be the following:

* 5 GSU’s which includes the enclosure, computer hardware – sensors, LEDs, embedded system.
* 1 Garage Sensor Gateway (GSG) to be installed on the roof of the Innovation Den.
* An archive of the software to run the GSS – Arduino sketches, simulation.
* User manual on how to operate the GSUs and simulation
* The portfolio including all documentation of the requirements, design process, project learning, communications, design solution and references.
* All other documents produced throughout the two semesters.

Constraints:

* $1500 budget
* The GSU must be battery powered and last at least a year without recharging
* The communication between GSUs must be wireless
* Communication must be capable of penetrating concrete and brick walls
* The GSU must be within 4”x4”x4”

# Project Plan

## Team Members

Nikolai Tiong

Roles

* Team Leader
* Mesh network design
* Mesh network testing
* Documentation

Zane Goodrich

Roles

* Sensors for the GSUs
* Hardware design – sensors, power
* Hardware testing
* Documentation

Tyrel Parker

Roles

* Processing received data from GSS
* Simulation Software
* Hardware purchasing
* Documentation

Joel Berain

Joined Spring 2020

Roles

* Organizing the Wiki page
* Getting caught up on the project
* Documentation
* Encryption of messages

# Concepts Considered

## Wireless Transmission

The distance between the garage and the Innovation Den is approximately 400 ft. There is Line of Sight between the second and third floors of the garage to the Den’s rooftop where the GSG will be mounted. The garage is constructed out of concrete which greatly reduces the signal strength of wireless signals. The Den is constructed of out brick which does the same. There is also the power requirement which means the wireless technology used must use low power while still covering the distance required.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Range - Urban | Power Usage (Transmitting) | Frequency | Notes |
| WiFi | 50 m | 2-20 W | 2.4 GHz |  |
| Sigfox | 3-10 Km | 158 mW | 900 MHz | Requires SIM card  Service fee |
| Zigbee | 100 m | 100 mW | 868, 915 MHz, 2.4 GHz | Capable of forming mesh network |
| LoRa | 2-3 Km | 100 mW | 433, 868 – 915 MHz | Capable of forming mesh network |

WiFi has too short of a range and too much power usage.

Sigfox requiring a subscription fee ruled that out.

Zigbee has too short of a range.

## Microcontroller

A microcontroller will be needed as the base hardware due to their low power consumption, low cost and small size.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Current Usage (Sleep) | Processor | RAM | Storage | I/O Pins | Wireless Module |
| Arduino Uno | 30 mA | AVR 16 MHz | 2 KB | 32 KB | 20 | Separate |
| Arduino Pro Mini | 4.2 uA | AVR 16 MHz | 2 KB | 32 KB | 20 | Separate |
| Arduino MKR WAN 1310 | 104 uA | SAMD21 48 MHz | 32 KB | 256 KB | 20 | LoRa |
| ESP8266 | 20 uA | L106 80 MHz | 32 KB | 512 KB | 16 | WiFi |
| Raspberry Pi | 100 mA | ARM 1.5 GHz | 4 GB | Variable >1 GB | 40 | WiFi |
| Adafruit Feather M0 | 300 uA | SAMD21 48 MHz | 32 KB | 256 KB | 20 | LoRa |

The Raspberry PI and Arduino Uno use too much power to be usable.

Everyone in the group has taken CS443 and is familiar with using the Arduino Uno. We purchased some Arduino Pro Minis first and tested them out. We had mixed results with them with being unable to power them on and upload sketches.

The next board tested was the MKR WAN 1310 which had a built in LoRa board. At this point we had decided on using LoRa with the Radiohead Library. However, upon testing it, it was revealed that the LoRa radio on this board does not support Radiohead.

## Battery and Power

The battery needed for fit in the 4”x4”x4” enclosure and leave enough space for the other hardware.

Concepts considered:

* Combining AA or D batteries in series and parallel
* 3.7 V LiPo battery packs
* Purchasing 18650 Li Ion batteries and creating our own battery packs
* Adding solar panels to supplement the battery
* Putting the microcontroller to sleep always when not in use and only waking on a timer or interrupt

A battery of 10,000 mAh capacity was calculated as the minimum needed. See the appendix for assumptions, parameters and the calculations.

Combining batteries to create a battery pack involves too much risk with internal resistances and different voltages for each individual battery possibly causing issues with discharging and were ruled out.

## Enclosure

## Simulation

## Encryption

Data encryption will be implemented for data packets being sent and received across the network. Encryption is used for data security. There are two main purposes to consider for data security across our network:

* **Data Concealment:** Data that it is flowing throughout the network could be intercepted by an unwanted entity. To protect this data, encryption can be implemented to scramble and hide the “actual” data that is being sent. This will increase data security over our network.
* **Data Authorization:** When receiving data across our network, a data packet sent by an unwanted entity could be intercepted. To help avoid this problem, data packets could be “stamped” with an indicator that shows it is an authorized packet for our network. Data being sent can be configured in a way that when it is received it can be first checked for authorization before it is interpreted. This will not only help secure our network, but also avoid waisted time and resources on data that was not authorized by our system.

Many existing encryption libraries can be found that can be implemented into our network. We could use one of those or create our own encryption class. If we create our own, there are also many encryption methods to consider (e.g. Private or Public key).

# Concept Selection

## Wireless Transmission

Of the 4 options considered, LoRa fit the requirements the best. It was capable of the range we needed and used low power. It also made use of the Radiohead library that Dr Shovic suggested that we consider using. We purchased some Adafruit LoRa radio modules and tested them out on Arduino Unos and Megas. This was successful when taken out on a field test between the garage and the Innovation Den, as well as within the garage. Nikolai also found a mesh network implementation that could be used as a base to build upon.

## Microcontroller

The Adafruit Feather M0 was selected as the microcontroller after the plan to use the MKR WAN 1310 fell through. However, this didn’t happen until January 2020 which left little time to obtain and test another board.

## Battery

Due to the difficulty in sourcing a large enough battery, the battery decided upon was a 2500 mAh capacity one. The uptime of the GSU would be timed and then extrapolated to determine how large a battery would be needed to last a year.

Adafruit has multiple components that can be combined to provide solar charging. They have 1W 6V solar panels, the charging unit with regulator, JST connectors and battery packs. The solar panel will not provide much power since it will not be in direct sunlight, but is something can be added relatively cheaply: $40 per GSU and help squeeze out as much battery life as possible.

## Enclosure

## Sensors

## Simulation

## Encryption

Our very own encryption class will be created to provide data security across our network. It will implement a private-key method to conceal the data, and it will add a data message at the beginning of each data packet to provide data authorization.

To fulfill each purpose of our encryption class the following will be implemented:

* **Data Concealment:** At this stage of development, the data flowing through our network is not considered “sensitive”. If data from the network is read by an unwanted entity, it would not be considered a high-risk security threat. Efficiency of data interpretation is probably more important to our network at this time. Implementing a simple, yet sophisticated, encryption method should suffice.

The encryption class will consist of specific multiple private keys. It will have a predetermined pattern that instructs which key to use at each stage of the encryption/decryption process. The keys can be changed internally if needed.

* **Data Authorization:** For data authorization, a simple phrase will be chosen to add at the beginning of each data packet. Each message being sent across the network will be tagged with this phrase, so each message being received will recognize that data packet as an authorized message.

# System Architecture – 2+ pages

Base Unit

Adafruit Feather M0 with RFM95 LoRa Radio – 900 MHz

Features from Adafruit Site: <https://www.adafruit.com/product/3178>

The Adafruit Feather comes with a built in LoRa module capable of running the Radiohead library.

* Describe the conceptual design – justify continued development
* Describe the components and how they are integrated
* Highlight novel features – your “value added”
* Explain how does each major component satisfy requirements

# Design Evaluation

## Vehicle Detection and Indication

The unit needs to be in an active traffic/parking zone and monitored to verify the following:

The LED indicator will blink Green periodically, to indicate that the stall is empty. It will need to do this while the rest of the system is asleep. Upon the detection of a heat signature (vehicle) it will wake, triple-verify that the vehicle has entered the space, and change the indication color from Green to Red. It will then need to go back to sleep and blink Red periodically, while the system is asleep, and until there is a change in the stall.

Various vehicles will need to be verified to ensure that all types are detected, and that the radius of the PIR as well as the range of both the PIR and Ultrasonic sensors are catching any vehicle, while also not updating falsely due to the presence of a vehicle that is not within the lines of the stall in which this particular unit operates.

## LED Indication

The LED always needs to be visible. This means testing its visibility during the morning, afternoon and night. The LEDs on each of the units should not drift so much as to cause a strobing effect in the garage.

## Hardware Enclosure

The enclosure for the parking unit should be tested on a similar surface to that of the parking garage ceiling, with different strengths of mounting tape, to ensure that it holds indefinitely, without the risk of damaging a vehicle or damage to the surface on which it is mounted. It will need to be placed in a test area and left for enough time to ensure that it is still holding strong and will continue to do so.

## Mesh Network

These are the milestones and things that need to be tested on the Mesh Network to conclude that it is performing as expected.

GSUs can transmit data to the GSM either directly or via another GSU. GSUs wake up on a timer to transmit, then go back to sleep. The GSUs and GSM need to be in sync with one another to send and receive data. The receiver is only going to be active for a short period since it uses ~20mA while active.

The GSM can transmit data to the GSG at the Den. This needs to be done on a periodic basis to clear the memory of the GSM since we don’t have a lot of memory to work with.

Data transmitted is encrypted – the payload needs to be encrypted since anyone with a LoRa radio would be able to receive the packets and decipher them. Especially since some of the messages will be control signals.

## Data Collection

The GSUs need to be able to store the sensor data and a timestamp. The GSM will transmit data to the GSG as it is received.

The server in the Den will permanently store all data that comes in.

Data will also need to be collected to calibrate the vehicle detection software. This means recording the average time that a commuter takes to park, to leave and the duration in which their vehicle is occupying a stall.

## Data Analysis

The Simulation must take in this data to analyze and so that it can work out average time from car entry to carpark occupancy.

## Testing Results

The final COVID-19 affected product produced the following results:

Sensing Vehicles

* The GSU was assembled and an enclosure created
* The GSU was tested by placing it above the ground in Zane’s garage and connected to mains power
* The GSU indicated a green LED to show that the space was open
* The sensing was tested by driving his truck forward into the garage, once the vehicle was under the sensor, the LED changed to green
* After reversing the truck, the LED changed back to green

Networking

* The GSU created a message to send every 10 seconds
* The message used the format that was originally created (this was redundant for this test however). This consisted of the <1>, GSG ID, GSM ID, GSU ID, parking stall status and the date timestamp in UNIX time. The <1> is an identifier to let the GSG know the message is to be forwarded to the MQTT server.
* The Dragino GSG received the sent message and forwarded the message onto the MQTT server via the internet at Tyrel’s house

Simulation

* The MSTT server receives the GSU message and parses it
* It then sends the data to the simulation software
* The simulation then updates the stall status
* The status of the parking garage can be viewed in real time via a webpage

Given the circumstances, the testing results are considered a success: the key requirements of sensing vehicles and indicating whether a car was in a stall, as well as displaying a simulation via a web browser was successful. The testing to get LoRa communication between Nikolai and Zane’s house was unsuccessful, however, this range requirement far exceeded the original requirement of 400 ft.

# Future Work

Due to COVID-19, the original design was not implemented. Many features were missing from the final test used for the Expo presentation.

Features Implemented

* Sensing a vehicle using ultrasonic and PIR sensors
* LED indication of parking stall status
* Point-to-point communication over LoRa – 2x GSU to GSG
* Addressing scheme over LoRa
* LoRa message format
* GSG to MQTT communication over internet
* Simulation
* Real Time Clock for timestamps

Features Not Implemented

* Battery requirement was removed and never tested
* Sleep and power usage reduction
* Solar panel and charger were not purchased
* Encryption
* Mesh network – changed at start of Spring 2020 to a star topology network
* Star network – long range communication of 1.25 miles was inconsistent and point-to-point was used

A future group project should work on the following:

* Build the star network with multiple GSUs communicating with the GSM
* Synchronize the GSUs so that there isn’t more than one transmitting to the GSM at a time
* Implement the sleep and waking up from an interrupt from the DS3231 RTC
* Implement the encryption module
* Reduce power usage
* Revamp the GSU enclosure and add the solar panel
* Modify the simulation to reflect the garage’s layout
* Source a battery

# Appendices

Supporting documents to long or detailed for main body

* Calculations, drawings
* Large tables, figures
* Computer programs
* Vendor data sheets
* 1-page Project Schedule in Excel (as executed at end of project)

## Battery Power Calculations

I create a spreadsheet with the different types of ways that the battery is going to be drained in the GSU. I then do some estimates as to the power usage based on datasheets and how often each will be used in a day.

The following assumptions were used:

* 10,000 mAh battery
* 1% battery drain per month due to self-discharge
* Transmission over LoRa will be at 50% power – 50mA
* Receiving over LoRa uses 20mA, there will be a 20 second receive window when a GSU is receiving
* A transmission from GSUs to the GSM will be every 30 minutes between 6am and 8pm
* Sensors activate on interrupt and will run for 10 seconds at a time
* The PIR sensor activates when a car parks/motion is detected
* The ultrasonic sensor will be used when a car is parked every 30 minutes afterwards
* A 10% duty cycle for the LED will be used, which corresponds to 10% of a 30mA LED
* The Arduino will be using current when active
* There will be a constant current drain when in sleep mode
* Solar charging is currently unknown and will not be included yet

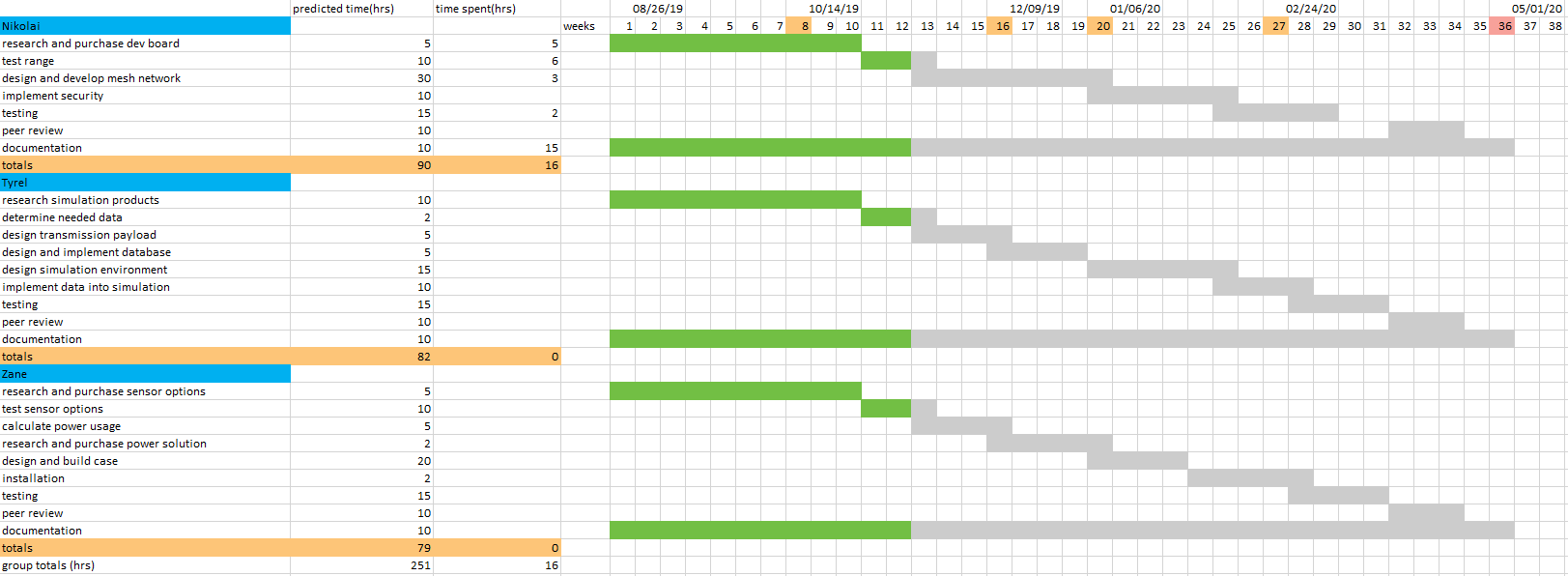
Parameters:

* Days per year 365
* Frequency per hour 2 (LoRa and sensor)
* Frequency per hour 3600 (LED)
* Hours active per day 14
* Days per month 30
* Available capacity on a 10,000mAh battery is 8,800mAh after accounting for the self-discharge

We need to aim for an idle current draw of 270uA in order to last for a year before we consider solar charging.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Current Used (mA) | Duration (s) | mAh per Day | mAh per Month | mAh per Year |
| Transmitting | 50 | 1 | 0.39 | 11.67 | 141.94 |
| Receiving | 20 | 30 | 4.67 | 140.00 | 1703.33 |
| PIR | 2 | 10 | 0.16 | 4.67 | 56.78 |
| Ultrasonic | 6 | 10 | 0.47 | 14.00 | 170.33 |
| LED | 20 | 0.05 | 2.00 | 60.00 | 730.00 |
| Arduino (Blink LED) | 30 | 0.05 | 3.00 | 90.00 | 1095.00 |
| Arduino (LoRa, Receiving) | 30 | 30 | 7.00 | 210.00 | 2555.00 |
|  |  |  |  | Total Used (mAh) | 6452.39 |
|  |  |  |  | Remaining (mAh) | 2347.61 |
|  |  |  |  | Idle Draw (mA) | 0.27 |

## Original Schedule



## Shared Folder Structure

Client Meetings

Documentation of meetings with the client: Dr Shovic.

Fall 2019

All documentation, submitted to BBLearn or otherwise created, from the Fall semester. Includes the project portfolio submitted in February 2020 documenting the first semester.

Programs

Contains all the Arduino sketches, libraries and simulation software created during the project. Includes instructions on how to operate the hardware and software.

Spring 2020

All documentation, submitted to BBLearn or otherwise created, from the Spring semester.

Team Meetings

Documentation of all team meetings.