# Project Mesh Network

DESIGN DOCUMENT

NetStruction


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# List of Symbols and Definitions

- CAN Bus: Connector Area Network Bus. A serial bus protocol for reading data from (typically) vehicles.
- OBD2: On Board Diagnostics (version) 2: A diagnostic connection and port standard to a vehicle's computer. Accesses data like speed, coolant temp, RPM, throttle position, etc.
- Pi/Pis: Singular and plural shorthand for Raspberry Pis.

NOTE: This template is a work in progress. When in doubt, please consult the project plan assignment document and associated grading rubric.

# 1 Introduction

## 1.1 Acknowledgement

The Mesh Network team would like to show appreciation to Danfoss for providing us with the expertise and hardware necessary for working on this project. We would also like to thank Craig Rupp for providing additional insight as our advisor and proposing a variety of useful technologies. As students we want to thank all involved for this opportunity to put our skills to use in a practical application, and to experience project development and management in a professional capacity.

## 1.2 Project Statement

Using a mesh network in a jobsite involving heavy equipment and/or a variety of vehicles is already a common practice. Collecting information and distributing it over a network allows managers to be better informed of the condition of their work which allows them to make better decisions regarding various operations. Information such as vehicle fuel level, location, etc. can be monitored to optimize the workflow of the job. These networks are only applicable in areas that support internet connections. This projects goal is to give job sites that lack this internet connection and provide them with the same information collection so they can improve those locations as well.

With internet each vehicle can connect directly to a service to transmit its collected data to a point where it can be processed and redistributed to those users that can utilize that information. Our mesh network solution is going to have those vehicles connect to each other rather than a global connection, and form a chain of communication connecting back to the users that require that information. In this way, work areas that don't have the conditions necessary for a data network can achieve the same benefits as those that do.

There is a market for companies that go out to under-developed countries or regions that don't have easily accessible internet/cell service. These companies are the target users of this project with our intention being to help them improve their operations through data collection and predictive services being performed locally. Users of this system will be able to install devices on their equipment that collect data and collate it into a hub where they can view that data in a meaningful format. Information such as fuel level for each vehicle can allow those users to optimize the paths that fuel delivery vehicles take which will decrease the slack time of each vehicle, decreasing the total time taken in a project. This is one of many aspects our users can take advantage of with this system.

## 1.3 Operating Environment

The operating environment will be the construction worksites that have limited access to network connections including cellular. Raspberry Pis will be used to facilitate the data collection and communication. These worksites can vary dramatically in size in terms of vehicles in use which has important design implications. Vehicles in use by the environment are varied in terms of operation data and importance. Work conditions within each environment can be quite different from other environments, resulting in different complications for each location.

## 1.4 Intended Users

This system is designed to provide a method for collecting and using information in an area with only the use of local networking. Therefore the intended users for this system are primarily companies/operations that are having to work in an environment where there is little to no internet or cellular service. An example of this would be in an underdeveloped country where a company may be creating roads to connect places of interest. In this scenario there wouldn't be reliable connection to the internet without the use of a satellite phone. To that end the network will connect the vehicles being operated by the company in this area through wifi and share the information they are collecting with each other and take this information back to a hub. There a manager(s) can utilize this data to track resource expenditure, equipment condition, and work being performed.

## 1.5 Assumptions and Limitations

Assumptions:

- After the members of this team have graduated, the project will be handed to Danfoss to be maintained and improved.
- End users will be able to understand the information collected and its implications.
- End users will have a device that will have software installed on it to operate as the central hub.
- The system will be modifiable to fit a wide array of applications/work.
- Each device installed on a vehicle will attempt to collect data 24/7.

Limitations:

- The project will use a raspberry pi device.

- Since collecting actual vehicle data is impractical, this data will be simulated.
- The system must function on a variety of devices.
- Only one month of data per vehicle will be stored on each device.
- For our purposes, a range of at most 100 meters will be tested

## 1.6 Expected End Product and Deliverables

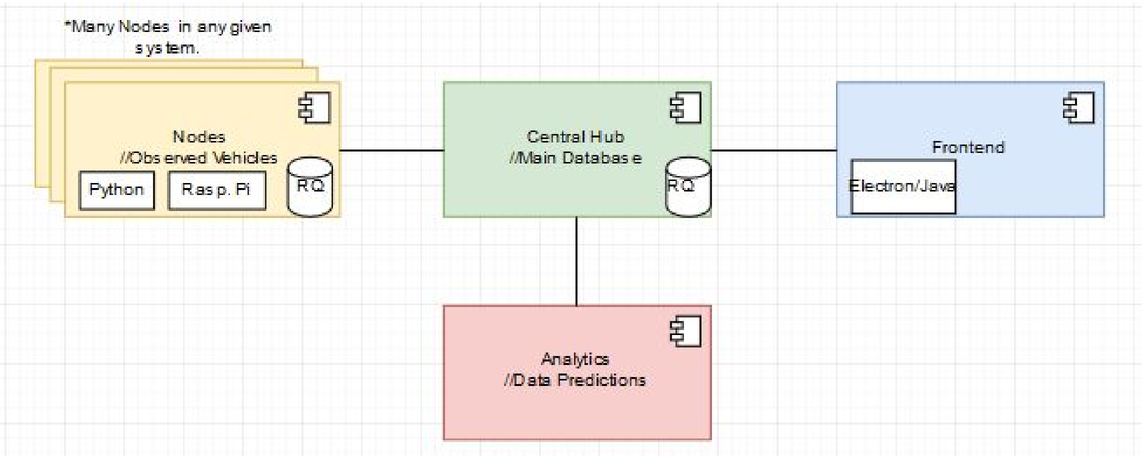
There are three major deliverables to this project. At the end of the first semester a functional prototype that demonstrates the technologies we have chosen work together to achieve the goals of this project will be delivered. Towards the middle of the second semester a Proven Concept will be delivered, which should have all major components of the system functioning and working in tandem. Our final product delivered at the end of the second semester before we graduate will be a Hand-Off version of the system, so that Danfoss can take the project and modify/improve it for use in the field.

- Prototype - December 5th, 2018
    - Prototype will demonstrate the use of RQlite to store and distribute the information.
    - Each raspberry pi will be able to connect to each other and transmit data.
    - A central hub will be able to connect to any raspberry pi and collect the data.
    - The central hub will have a preliminary means to display the data to an end user.
    - A demonstration should be available to show the client the results of this prototype.
- Proven Concept - April 1st, 2019
    - Each raspberry pi will simulate field data and connect to each other device when necessary.
    - The central hub will have an complete front end application that displays the data in readable and meaningful manner.
    - Predictive analysis is being used to take the data collected and further assist end users in utilizing the information to improve their operations.
    - A demonstration of the complete system's facilities should be available to prove the results to the client.
- Hand-Off Version - May 1st, 2019
    - After all required aspects of the project have been completed, the focus will be to completely document the system and make it easily understood and configurable by the teams at Danfoss. If possible, devices should be interchangeable and the network should be flexible in terms of size, data, and device type.
    - All documentation will be prepared for transfer.
    - All code will be finalized and documented well.

- Modification and manuals for both software and hardware information will be prepared and available.

# 2 Specifications and Analysis

## 2.1 Proposed Design




The main requirements of the project are:

- ability to support a large number of nodes within a network
- ability to add and drop connections rapidly
- support a network of devices with no internet connection
- nodes must collect at minimum five types of data concurrently
- data must be shared between all nodes within the network

We have identified a few potential approaches for solving the needs of the mesh network problem. In particular we needed to identify a method to create a mesh-network without access to the internet. The first idea is the basis for some of our other ideas, that being a central hub that can connect to nodes attached to machines. This central hub is where all the information from the vehicles will be collected and stored for use by the end-users. Each node will be able to collect information from the other nodes in the network, creating and removing connections rapidly as the nodes move around physically. By having each node collect the other nodes information, only a single node needs to connect to the central hub to transmit the data. To assist this idea process we have two other potential solutions. First of these is a drone that will operate as information ferry, running a circuit of all the nodes, collecting their information, then depositing it back at the central hub. Another idea is to have node pylons, stationary points that create a line out to the operational areas of the vehicles. Both of these solution additions address the problem of limited range of connections, but may not be necessary after testing. The frontend  and data analysis will be developed further during the second part of the project, and due to the modeling of data being easy to abstract solutions to those aspects will be explored at a later date.

Currently we have researched and started working with Raspberry pis, RQLite, and various connection methods. The raspberry pis will make use of sensors to collect data, and we currently setting up linux distributions on those in preparation for that. We are installing RQLite on those Pis, for this purpose of using its distributive capabilities in sharing their database information. For the connection methods we are exploring the possibilities of wifi, zigbee, and bluetooth. We will document the range of these and their ability to connect rapidly on the nodes, and determine through that data which of the methods is an optimal solution.

## 2.2 Design Analysis

We have not yet entered the testing phase of our designs and prototypes. Currently, we are developing the prototypes that will be subjected to these tests. The tasks we have accomplished thus far are:

- Decided on the data storage method (RQLite)
- Picked our starting network method (WiFi)
- Setup the devices we will be using as nodes (Raspberry Pis)
- Ordered the hardware we need to build our prototypes (sd cards, cables for Pis, various sensors)
- Began developing a desktop application for accessing the local data (Javascript and Electron)

With our initial design decisions, some of the inherent strengths of the decisions we have made are-

- Raspberry Pis have plenty of supporting material online for working with CAN bus data
- Rqlite allows us to circumvent the process of structuring data in JSON or protobuf format
- Rqlite is also Sql based and our group has a good amount of experience with Sql already
- Wifi is the most common type of connection type for mesh networks and has plenty of supplemental materials online that we can use

As we progress, we plan to swap potential technologies and methods out interchangeably, stressing modularity in our design. This is because our project is largely proof of concept, we want our client to be able to create and use their own components within our project, mainly following the general structure we are defining. Throughout the testing of our project, we will provide feedback on each of the methods we test, but ultimately when we pass it off it is our client’s decision as to what they move forward with.

# 3 Testing and Implementation

## 3.1 Interface Specifications

Since the base of this project is that the network itself needs to be in working order we are going to use manual test to ensure they connect to each other over the network. This will be done by simply monitoring the hardware to verify that when it is able to connect to the network it does so. Testing the database will be slightly easier as automated test cases can be used to ensure everything works as planned.
An important technical interface important to our project is CAN bus. It is a bus standard designed for vehicles. We will need to learn the proper way to parse and store/send the data coming in from the CAN bus, as well as make sure the drivers and connection to the bus module are functional.

## 3.2 Hardware and software

We will be be using an OBD2 Emulator to test, assuming we can acquire one. This will give us an ability to input the appropriate live data into the system. In addition, or if we cannot get an OBD2 emulator, we can test the system using our own vehicles, by plugging in a 3-6 of the Raspberry Pis into our cars and using the actual data from the cars as we drive.

Test cases developed for RQlite will be written in a mixture of NodeJS and Python. Nodejs will be used to generate the test data and simulate machines moving around and different data types coming in. The Python will provide the scaffolding for the actual test cases. It will contain what we should expect the system to do based on the defined test cases. Having automated test cases based on NodeJS and Python will help with project development because using them is integration testing. With each new feature developed we will be able to ensure systems that were working before additions still work after the integration.

## 3.3 Functional Testing

We haven't reached our testing phase yet, but our planned testing is as follows:

- To test the nodes collection ability, we are going to have them simultaneously take in five streams of data, simulating oil pressure, oil temperature, fuel level, hydraulic press, and gps location.
- To test the nodes ability to connect to each other and the hub, we plan to have at minimum three devices running, and turn their connections on and off to test the system's ability to manage the connections between each device.
- To test the central hub's ability to collate the information we will have at minimum three devices connected in sequence collecting and transferring data which we will make tests to verify that data is the same throughout each device.
- To test the system's ability to dynamically add nodes we will have a single device connected to the central hub and then start activating and deactivating nodes in sequences that will be specified at a later time.
- All of these tests will be performed without the devices maintaining an internet connection which covers the requirements of low to no internet within the system.

## 3.5 Non-Functional Testing

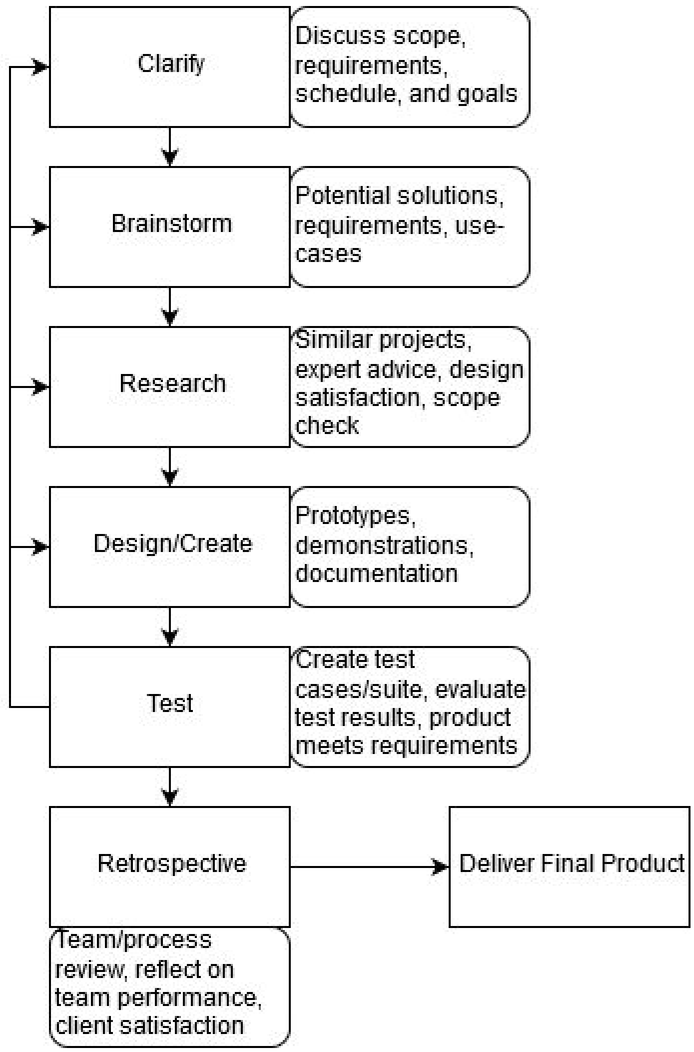
Performance will be stressed here. We will have to test the system latency to make sure the system responds to vehicle changes and updates the hub in a reasonable amount of time. Radek (our client) did not give us a specific time requirement, but he did say it should be, more or less, "Live".

The frontend will have to be extremely usable, because it will be monitored and operated by a construction site foreman. We can test this by letting friends/family use the software and give feedback. In addition to an easy to use frontend, we also need to make sure the hardware is simplistic and usable as well. Having an employee go out to connect our Pi to a port in a piece of machinery should be about as complex as it will get.

Security is going to be another important area to test. We need to ensure that the only devices that are authorized are attached to the network and all others are barred.

## 3.6 Process

Since the systems in Section 2 have yet to be developed the test for said systems do not exist either. The process of creating the test and the overall development of the project will follow the following design process.




## 3.7 Results

To quote the design document template:

> "This part will likely need to be refined in your 492 semester where the majority of the implementation and testing work will take place."

In other words, our implementation of the project is still in its infancy or, perhaps, it's conception. As we have yet to implement any part of the project to a testable state, we do not have any test results.

**Modeling and Simulation**:

- At this phase of the project we have nothing to report here, once we get the Pis set up and start to connect them all, then we can begin to design some models to show off different physical arrangements of the nodes.

**Implementation Issues and Challenges**:

- Implementation of the networking and data acquisition portions will likely involve some trial and error. As such, it will be important to be able to test our data in a way that reflects realistic use. This will add difficulty because our resources limit us to a small number of tracking devices. Additionally, we do not yet have access to emulators for CAN or sensor data.
- Setting up each device as a router that recognizes each other device individually will present a challenge
- One of the Challenges will be getting each of the Pi's to allow network connections as an access point. As well as successfully identify other Pi's and pick one to connect to that will optimize the network connectivity. This will require a lot of system level network configuration that will be new to our team.

# 4 Closing Material

## 4.1 Conclusion

At this point in time, our team has firmed up our list of deliverables with our client and received preliminary hardware to begin work with. From this stage, we will begin loading up our Raspberry Pi's with the base software to get started, connecting to Rqlite and learning to work with it, and starting on a base UI application with Javascript and Electron. By week 10, we hope to have some base deliverables with each of the deliverables listed above, and plan to have finalized all of our design decisions firmly. We have now moved from the research and conceptual phase and entered into the base implementation phase, but we feel confident about what we need to do. At the moment, things still look hopeful.

## 4.2 References

<will be done later, will include the website of the technologies used, pricing sources, previous projects examined, etc.>

## 4.3 Appendices

<will be done later, libraries for each of the languages / frameworks/ tools will be included here as things progress.>