Group 13 – S.H.E.M.S.
Smart Home Energy Monitoring System

Final Paper

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1.0 Executive Summary

There is an energy crisis in the world, not only in the transportation section but also in generating, distributing, and consuming electricity. Adding more gadgets and devices that are power hungry into our everyday life increases the energy consumption even more. The field of power efficiency is not progressing at the same rate that we consume power. This is why there are many researchers investigating and working on getting more energy from different resources as well as ways to save the energy we currently have available.

Our idea for the project focuses on making consumers of electricity aware of the consumption of energy and how some gadgets and devices are eating energy inadvertently, mainly focusing on something called phantom energy, or better explained, when an electronic is not completely off.

A small low power device that is able to monitor and track your power usage (in dollars amount). We should have several monitoring devices (the same power device) and a single central HUB that they all communicate with. We plan to have an LCD display to display this information to the user on (what information). We plan to incorporate a relay inside of each monitoring device to cut off power to a device (either by power surge, non-use of the device to avoid phantom energy, or by wireless control from the phone of the user). This way the device can truly be off and no longer using any power. We anticipate this will be most helpful for computers, monitors, televisions, Blu-ray players, as well as smaller appliances and devices. We plan to gather and store (the data obtain from these devices, including power consumption, peaks in voltages for future reference, for a period of 10 years) the data of usage for the devices plugged into the monitoring devices. Then we plan to transmit this information to the central HUB every hour or when the central HUB requests it to be sent if the user wants to know sooner (This with the purpose in mind to keep track of spending habits of electricity, if it is making the bill much higher than usual and/or the devices is using too much phantom energy). We then plan to store, and allow the user to view this information as they see fit to help them lower their power consumption.

We are looking to create an affordable and feasible way to allow everyone to reduce their energy consumption and their power bill. We plan to create a robust and reliable mesh network with the Bluetooth controlled devices that will allow the consumer to completely turn off items they are not using such as stoves, ovens, microwaves, dishwashers, washing machines, driers, DVD and Blue Ray players, TVs and any other items that are hooked up to the system not just off but completely off by disconnecting them from the power so as to keep them from drawing phantom energy when they are not in use. Some of these devices such as hot water heaters and pool pumps are already part of your EnergyWise Home program. These items can also be monitored and controlled with our system as well. This could allow for an option to have the consumer add some or all of these other items that are normally not on the EnergyWise Home program to it when they are not home, but even more importantly it could allow for them to be disconnected from the power grid completely. This would not only save them cash on their bill, but also

Duke Energy as Duke energy wouldn't need to produce the energy nor the harmful CO_2 emissions to power them when they are not in use by anyone. Below table 1 has a number of common items in terms of usage and cost.

Table 1: Electric Appliance Operating Cost List[i]:

Appliance Description	Wattage, Size and Usage Assumptions	Monthly kWh Estimate	Monthly Cost Estimate
Computer Monitor 17" CRT	80W, 2hrs/day	4.8	$0.39
Computer Monitor 17" LCD	35W, 2hrs/day	2.1	$0.17
Computer System left on	150W, 24hrs/day, PC, Monitor, and Printer left on with no sleep mode	108.0	$8.86
Dehumidifier, runs constantly	400W, 24hrs/day	288.0	$23.62
Dishwasher and Heater	1200W, 4 uses per week, Using heater to dry	10.3	$0.85
Fan Furnace, Fan	400W, 12hrs/day, Home ceiling, exhaust to attic	144.0	$11.81
Fan Furnace, Fan	**500W, 24hrs/day**	**144.0**	**$11.81**
Food Processor	400W, 1 use per week, 5 minutes per use	0.1	$0.01
Freezer old	450W, 24hrs/day, medium size	97.2	$7.97
Freezer new	335W, 24hrs/day, medium size	60.3	$4.94
Gaming Electronic	50W, 1hr/day, PlayStation 2	1.5	$0.12
Gaming Electronic	**74W, 1hr/day XBox Original**	**2.2**	**$0.18**
Hair Curling Iron	100W, 15 minutes/day	0.8	$0.06
Hair Dryer	1200W 14 uses per week, 5 minutes a day	1.0	$0.08
Heat Lamp	250W, 24hrs/day, always on, in a cold location	180.0	$14.76
Hot Tub, Electric	550W, 24hrs/day, heater left on, poorly insulated tub	1980.0	$162.36
Iron	1100W, 4 uses per week, 30 minutes	6.6	$0.54
Television, LCD	150W, 6hrs/day, 32" LCD of screen average size and wattage	27.0	$2.21
Television, Plasma	350W, 6hrs/day, Plasma of average size and wattage	63.0	$5.17
Washing Machine	665W, 8 uses per week, average for a family of four, 45 min, cycles (Does not include hot water usage)	12.0	$0.98
Water, Well Pump used for irrigation	1600W, 4hrs/day, 1HP	192.0	$15.74

2.0 Project Description

2.1 Project Motivation and Goals

The main motivation of the project is the reduction of the high cost of energy and the control over power at all levels including standby power or phantom energy. According to the Lawrence Berkeley National Laboratory, individual devices draw very little power and they cannot be completely off unless they are unplug. Most devices that have an external power supply, remote control, continuous display or charge batteries use up standby power. The amount of power used could range from 2 watts for a DVD recorder to 27 watts for an audio mini system. The amount of consume power that these devices could add to represents up to 10 percent of the total energy consumption of a regular household. The goal of our project is to reduce the standby power to a negligible amount remotely and safely and provide visual means for a user to realize how much power the devices connected to the smart meter are drawing.

2.2 Objectives

The main objective of the smart monitoring meter is to measure current, voltage and power accurately and safely. For this reason we explain the different alternatives of measuring power, their features and how safe they are or are not to us and anyone else potentially handling the smart meter.

Next objective is to automatically shut off the device when is not in use, this feature will help reduce unnecessary standby power and therefore energy and money.

Our final objective of this project is to give access to the users to information about their usage in a detailed but in an uncomplicated manner.

2.3 Project Requirements and Specifications

In order to save power, we require our device to be able to perform at a certain level and we want to specify what those requirements are. There are several components to which we need to specify the requirements for. The two main components are the satellite monitoring station and the central HUB. There are sub components to these main components and we shall discuss the requirements of those as well.

2.3.1 Central HUB requirements

The central HUB will be the central of the information as it has to be able to do the following:

- Must be able to request and receive data from the satellite monitoring station.
- Must be able to rework the power consumption data from the satellite monitoring stations

- Must be able to display the power consumption data from each individual appliance connected to the satellite monitoring stations.
- Must be able to communicate bi-directional with a mobile android device.
- Must be able to control if a satellite monitoring station cuts off power to a device or lets it have power.
- Must be able to take information from a touch screen and process it to decide what should be done.
- Must be able to store power consumption information for a period of at least 10 years
- Must be able to allow a mobile device to control the time and dates that any device in any order is either on or off
- Must be able to provide a calendar that helps the user understand how much power was used and when it was used
- User must be allowed to use a calendar to set times and dates where the devices are automatically shut off

2.3.1.1 Central HUB Microcontroller

Many of the requirements set for the central HUB can be accomplished by using a microcontroller. The microcontroller will be the brain of the central HUB but it also must be able to complete certain requirements.

- Must be able to connect and maintain a bi-directional communication with the satellite monitoring stations and a bi-directional communication with a mobile device.
- Must be able to support Bluetooth Technology.
- Must be able to use up ultralow power.
- Must be able to take in analog or digital data.
- It will calculate the average power over time.
- Calculate using the power calculations what the bill for this month will be.
- Calculate how much power was saved by switching devices off that would normally be on.
- Be able to switch the satellite monitoring stations on and off wirelessly.
- Be able to take in data from an LCD touch screen.
- Be able to output data on to an LCD touch screen.
- Have a storage device to store the data for long term and be able to access this data in the future.

2.3.1.2 LCD Touch Screen

To avoid working with buttons we have chosen to go with an LCD touch screen as it serves as a way to display the information needed to be displayed as well as interact with the device. This will be the default way of controlling everything taking into account that not everyone owns an android device.

- Be able to track at least 1 finger on the surface of the screen.
- Be able to display at the request of the user, the average power consumption.

- Be able to display at the request of the user, the monthly cost.
- Be able to display at the request of the user, what devices are on and off and their current power consumption.
- Be able to display at the request of the user how much money was saved.
- Must be easy to use the LCD interface.
- Must have a sleep function or a very low power mode in order to save its own power consumption

2.3.2 Satellite monitoring station requirements

The satellite monitoring station is like the hands and feet of the device. It collects the information. The appliances directly connect to these five devices. Even though it's the central HUB that sends the information that controls what the satellite monitoring station does, the satellite monitoring station is the one that physically cuts off the power or let the power flow. Also the satellite monitoring station measures the current and the voltage and uses this data to calculate the power before it sends it to the central HUB.

- Appliances must be able to be plugged into this device.
- Must be able to work with a maximum supply of 9V.
- Must be protected against power surges and EMI (Electromagnetic Interference).
- Must be able to transmit data digitally to the microcontroller.
- Transmission and accuracy shall be within wireless industry standards.
- Be able to shut off the appliance connected to it wirelessly and automatically.
- Must be able to measure the voltage and the current.
- Using the voltage and current, it must be able to calculate the power used by the device.
- Must be able to regulate the power used.
- Must be able to communicate with the other Satellite monitoring stations.

2.3.2.1 Current and Voltage measurement circuit.

The heart of the project lies in measuring the current and the voltage to calculate the power and so we can do everything else needed to be done with these two data. It is very important that this circuit works as intended.

- Be able to measure the current.
- Be able to measure the voltage.
- Be able to accurately time the measurement of the current and the voltage so we have them at around the same time for more accurate result.
- Be able to accurately measure the values and rapidly give an accurate value.

2.3.2.2 Relay

It is essential to save power that the user is able to control when a device gets power and when not. This is where the relay comes in handy as it can cut the power off from the device connected into the satellite monitoring station.

- Has to be small to not take up space on the Satellite monitoring station.

- Must be able to quickly cut off the power once the signal is received to do so.
- Must be able to remain in a certain position with low power consumption.
- Must be able to cut off the power going to the device.

2.3.2.3 Wireless Communication

We have 6 parts (or 7 if we include the mobile device) that all have to communicate with each other. The wireless device makes sure that all these devices can communicate with one another and that the user is able to control these devices wirelessly.

- Must have a range that covers a decent size house.
- Must have a strong signal that can pass through multiple walls that can naturally occur in a house.
- Must transmit the signal in an encrypted form to protect the device from security vulnerabilities.
- Must be able to communicate with a mobile device.

3.0 Research Related Project Definitions

We look at different existing projects and technology that is similar to what we plan to build in order to get a better idea what we are competing against and what is expected of a smart home and an energy management system. Although we look at a lot of very similar technology, we integrate specific parts of existing technologies in a unique way. The different product we will compare will give an idea of how our project developed and to give a bigger picture of what we are calling the Smart Home Energy Monitoring System.

3.1 Existing Similar Projects and Products

With the growth of semiconductor industry and the lowering of prices of technology, it is not a mystery that there was a need to make houses smarter and to monitor how much power is being used in the house. One product that does this is the P3 international P4400 Kill a Watt electricity usage monitor which is an existing product similar to what we intend to integrate in our system. This product is used to measure the current consumption from the main cables coming into the house to calculate how much power is being used. We will then take a look at the Aeon Labs' DSB09104-ZWUS-Z wave home energy monitor which is also very similar to the P4400 Kill a Watt. Another interesting and similar product is the Nortel Professional Edition Smart Metering Outlet with Power Factor LED Energy Saving Sensor. This device is used to measure power consumption and other variables of electricity used by appliances plugged into it which we will also integrate into our project. We are planning on having 5 of these devices with a Bluetooth integrated into them so that all can communicate with each other and with the central HUB. We will then discuss the Efergy Elite Wireless Electricity Monitor which is similar to the Aeon Labs' DSB09104-ZWUS-Z wave home energy monitor which measures the overall power consumption throughout the entire house. An existing similar project done by another group from last year is called A.U.M. and this was done by group number 13 and we will talk about this as well. They used one device that uses 5 outlets to measure and control the power to each device.

3.1.1. P3 International P4400 Kill a Watt Electricity Usage Monitor

We take an in depth look at the P3 international P4400 Kill a Watt Electricity Usage Monitor and discuss the advantages and disadvantages of this device and what are we incorporating into our design and what are we most likely to leave out. The P4400 Kill a Watt works by plugging it into any standard home outlet and connecting the device you wish to measure its usage data into the outlet of the P4400 Kill a Watt. The device has a built in LCD display that displays all of the meter readings. The meter is capable of measuring and displaying the Voltage, Current, Frequency, Power Factor, and the VA. The difference between the P4400 Kill a Watt and our monitoring station is that our satellite monitoring station do not have the LCD display and therefore not have the ability to display this information directly at the outlet where this device is plugged. Since we plan to make a smart home and an energy monitoring system we include almost all of these measurements the P4400 does. The voltage and the current measurement are obviously required to calculate the power and in turn the power is used to determine the kilowatt hour used based on the time the device was plugged in. The frequency and power factor is also useful in determining how efficient the device is performing. Even though our satellite monitoring station lacks the LCD display, we make our way around this problem by integrating a Bluetooth device and using this to send the information to the central HUB and from there process all the information and displaying this information. This way we prevent the user from having to check every single monitoring device individually. Here we have the technical specifications of the P4400 Kill a Watt Energy Usage Monitor. The ideal condition would be to have the same amount of accuracy, input power, max current, max voltage, and max power. For the dimension of our satellite monitoring station, if we manage to find a compact microcontroller and a Bluetooth device, seeing that we do not have an LCD display, we hope to decrease the length from 5.1 inches to around 3 inches. Another difference with our monitoring station is that it does not have the different buttons but merely a switch to manually turn it on or off.

Table 2: Technical Specifications for the P4400 Kill a Watt[ii]:

Accuracy	+/- 0.2%
Input Power	115 volts AC, 60 Hz
Max Current	15 amps
Max Voltage	125 volts
Max Power	1875 VA
Dimensions	5.1 inches long x 1.6 inches thick x 2.4 inches wide

3.1.2. Aeon Labs DSB09104-ZWUS-Z Wave Home Energy Monitor

This device is used to measure the power usage of the entire house. It has two clamps that are connected around the main incoming electricity cables even before it connects to the main breaker. It uses radio frequency to transmit data to your computer much like what we are planning to do. This device reports the usage in wattage and in kilowatt hours. The difference with what our device, it is sending the data to the central HUB and from the central HUB in is either sent to an android device or a personal computer. A problem that rose from this device is that if the circuit box is made of metal then the meter has to be installed on the outside since the Bluetooth signal would have difficulty going through this metal. A big advantage for this device is that there is no need for an electrician to install it; however the circuit box's main breaker has to be turned off in order to install the meter. This meter is essential in knowing the overall consumption of power through the whole house. Even though it does not provide an individual power usage for each appliance, it gives us the opportunity to keep the cost of the project low by limiting the amount of monitoring stations while still measuring the overall power that is being used. Another factor that we did not take into account was the weather resistivity of this device due to it being most likely installed outside of houses. To incorporate a similar system into our device we would have to take into account that this part of the project should be able to handle the changing weather and work in all weather conditions.

Table 3: Technical Specifications for the DSB09104-ZWUS0Z[iii]:

Power	90-260VAC, 50/60Hz
Weatherproof	IP43 rated
Range	24m

3.1.3. Nortel Professional Edition Smart Metering Outlet

Since this meter is used to measure the 220 voltage we thought about using a similar meter to measure the power of air conditioners that run on 220 voltages. However, upon further research we found that the amount of current an air-conditioner uses is above the 10A rating for this device. The device can be used to measure current up to 15A but not long-term. If we are to implement a satellite monitoring station that measures the power consumption of the air-conditioner, we would need a meter that can work at the 220 V and being able to work on the long-term at the 15A or higher. This device is similar to the P4400 Kill a Watt however it is designed to work at a lower frequency and at a higher voltage. From the specifications we can see that this device is slightly larger as well.

Table 4: Technical Specifications for the Nortel Professional Edition[iv]:

Accuracy	1.0
Specifications	220V, 50Hz, 2.5A-10A (to 15A can be measured, but not long-term measurement)
Meter constant	6400imp/kwh
Power consumption	≤ 0.4W
Weight	about 250g
Overall	158mm × 80mm × 50mm
Standard	GB/T17215-2003
Operating temperature	-25 to 45 ° C
The backlight	pure green (industrial grade) button is lit for 10 minutes,
Voltage	AC instantaneous voltage of the circuit under test (Unit V)
Current	AC instantaneous current of the circuit under test (in mA)
Active Power	The load active power (in W)
Power Factor	The power factor of the load **(cos)**
Cumulative power	Load the cumulative electrical energy (unit kWh)

3.1.4 Efergy Elite Wireless Electricity Monitor

Looking at this and comparing it to the Aeon Labs' DSB09104-ZWUS-Z wave home energy monitor we can see that this device works at a much higher voltage, has a similar range, and has memory. This device transmits the data to a separate device that you can carry around with you and monitor the power consumption from almost everywhere in or around your house. We had the same intention with our device. What we want to do is to send the information from the central HUB to your mobile device or to your personal computer and from there give you the options to turn on or off every individual satellite monitoring station to help you conserve power.

Table 5: Technical Specifications for the Efergy Elite[v]:

Frequency	433.52MHz
Transmission Time	6s, 12s, or 18s
Transmission Range	40m-70m
Sensor Voltage Range	110v-300v
Measuring current	50mA -200A
Accuracy	<8%
Memory	64K

3.1.5 The Automated Utility Management

This was the project of group number 13 in fall and spring semester of 2012-1013. Although very similar to our project there are some key differences in our design. The Automated Utility Management or A.U.M. for short has 5 output which are all protected with surge protector, an LCD touch screen, an infrared sensor, and a Bluetooth feature to communicate with an android device. They also had the feature of taking the average power by hour, day, and month and show it onto the LCD touch screen and let the user interact with them and further decide using this data on how the user would control the power in his house. They had an infrared sensor to sense if there is someone in the room in order to set some additional features where the power could be cut off to all devices if there was no one in the room. First of all, we removed this feature from our design since there are difficulty with being able to track and test for an empty room. Trying to check for an empty room is not as easy as it sounds since there are a lot of scenarios that could arise and to test for all of them and how would we make sure the system works is just a huge problem on its own and considering the added satellite monitoring station to our design we decided to let this part out. Another key difference is that we decided instead of having only 1 device that connects to all of your devices and running long cables to each device, we make 5 smaller satellite monitoring stations that can communicate wirelessly to the central HUB that has a similar LCD touch screen with the hourly, daily, monthly and possibly yearly power consumption and money saved. The reason behind 5 individual satellite monitoring station is that it is much more convenient to have each device plugged in where they are being used instead of needing them to be close to one another. The removal of the infrared sensor is compensated by clever software design where the user can add intervals of time where they are assured that they do not use the devices or by manually controlling this through their mobile android which is another feature we decided to use in our own device as well.

3.2 Relevant Technologies

After looking at all the different similar existing products we piece together the component and technology needed to make our project idea come to life. We need an adequate power supply for our central HUB and knowing that this contains the main LCD screen we would need a power supply that is either portable, or lasts very long, or is rechargeable, or uses power directly from the outlet. Another essential part of our design is the wireless networking. We look at different wireless devices including Wi-Fi and Bluetooth technology. There are two parts to our power monitoring device. We make 5 identical satellite monitoring stations that communicate with the central HUB and perhaps with each other. We also purchase and integrate a meter that measures the power consumption from the main electricity cable so that we can calculate how much power is being used overall which also wirelessly transfer the data to the central HUB. For the actual measurement we use a current and a voltage meter and from these two we can figure out how much power is being consumed as time passes. To protect the satellite monitoring stations and the main electricity monitor station from surge and getting fried, we add surge protectors. In order to cut off power to devices that draw phantom power, we have to include a relay. We also make use of the wireless network to control the relays and give the user the ability to wirelessly turn the device connected to the satellite monitoring station on or off.

3.2.1 Power Monitoring

For monitoring the power consumption we plan on using a similar device to the P4400 Kill a Watt Electricity Usage Monitor. For the present design we need an input voltage range of only 90V-150V AC to cover any fluctuations occurring at the input voltage. Since the whole purpose of the satellite monitoring station is to measure the power consumption and improve the energy efficiency by turning of the device while it is not being used and still drawing power, we would like a very accurate measuring device with low error compared to the -/+ .2% of the P4400 Kill a Watt. Prior to sending the data to the main HUB we would want to process the data using a microcontroller that uses the measured values for voltage and current and perhaps frequency to calculate the power consumption and performance of the individual device. The power usage is wirelessly sent to the central HUB where it is displayed in different time variations like usage per month or per hour or per day.

3.2.2 Wireless Networks and Communications

Communication amongst the satellite monitoring station, the main electricity cable monitoring station, as well as the central HUB is critical in order to have a functioning smart home and energy monitoring system. The wireless network we plan on using is Bluetooth since it has the advantage of being low power consumption, and transmits the data securely, and it is also very inexpensive. Bluetooth has the advantage that it can communicate to several devices at once which is very useful when we have 5 satellite monitoring stations, possibly 1 main electricity cable monitoring station and a central HUB. When we have all of these devices communicating with each other we can develop error checks between the network of devices and in doing so we can prevent collecting corrupted or unwanted data or even notify the user that something went wrong with a particular device. In order to make it easier for the user to monitor the power consumption, we plan to allow the central HUB to communicate with a mobile device or a personal computer given that these have the Bluetooth feature on them. We are looking to have the Bluetooth communication to work at a maximum range of 50 feet.

3.2.3 Electronics Power Supply

The satellite monitoring stations need a power supply to work and most likely use the electricity coming from the outlet as their power supply after being transformed and converted. The main concern is supplying power to the central HUB and the main electricity cable monitoring station as these will not be connected to the home outlet. Similar to the Aeon Labs DSB09104-ZWUS-Z Wave Home Energy Monitor we may use 4 AA batteries to power the main electricity cable monitoring station. Instead of using regular batteries we can use rechargeable long lasting batteries that don't require replacement or a recharge for a long time. For the central HUB we are required to provide power for the microcontroller and the LCD display which is the element that draws the most power. There are 2 options for supplying the power to the central HUB. We either use a rechargeable lithium ion battery which can last up to a week before having to recharge it, or we can have the central HUB connected to the home outlet and transform and convert the electricity to the required amount.

3.2.4 Power Surge Protection

To protect the appliances as well as the entire Smart Home Energy Monitoring System from instantly getting fried in the event of a power surge, we will add surge protectors to every device that will use power from the home outlet. A decent surge protector working at the 120 voltage and having a clamping voltage of 250 V will assure us that this device will still work and measure irregular voltage patterns but as soon as it becomes a clear power surge that the surge protector will kick in and cut off power to the devices. In this, case having the central HUB working on emergency battery as well as using the home outlet for power is advantageous. If a power surge occurs and the surge protector shuts down all of the satellite monitoring station, the central HUB which would still be running on battery can notify the user of the recent power surge and allow the user to check for any power failures around the house and when it is safe to turn the satellite monitoring stations on again he can do so as well.

3.2.5 Relays

One of the key features of the satellite monitoring station is the ability to cutoff power to the appliance either setting up a particular time at which the appliance will have his power cut off or by having the user wirelessly giving the command to cut the power off or having the user manually pressing the power off switch on the satellite monitoring station. Either one of these features will be using a relay. Since the central HUB will have a memory drive, we can incorporate time of days and days in a week or in a month or even any particular moment on a calendar when a particular relay should cut off power to any one or all appliances connected to the satellite monitoring stations. As the central HUB gathers more and more data, it can suggest optimized times for the relays to cut off power or return power to a particular appliance.

3.3 Strategic Components

To have a finished product there are strategic components like the current transformer current sensor, an MOV surge protector, and a voltage regulator. The current transformer current sensor would be an ideal device for measuring the current flowing through the wire since it will not require cutting the wire. The MOV or Metal Oxide Varistor is to protect our devices and make sure nothing gets fried as soon as we connect it to power. Lastly, the voltage regulator is used to regulate and stabilize the voltage coming in to and going out of the satellite monitoring stations so that we can accurately measure the power consumption using a more stable voltage.

3.3.1 CT Current Sensor Input

For the main electricity cable monitoring station we would need the use of a CT current sensor since it would eliminate the need to cut through the wire to hook up the series current meter and allow the user to easily install the current meter without the need of an electrician installing it. A current transformer current sensor also allows the user to measure the voltage given that there is a burden resistor so we not only tackle the problem of having to measure the current but also the voltage at the same time.

3.3.2 MOV Surge Protector

The Metal Oxide Varistor or MOV for short is a surge protector that uses semiconductor materials to operate. We need a surge protector that will protect our electronics at about 300-400 volts. The surge protector will create a short if the voltage given is higher than its rated voltage. The surge protector will be crucial even during testing as it will protect our circuit from bad wiring or mistakes that we might make during the building of the device. Not only will this save us time but it will also save us money and not only us but also the consumer of our product who would not want a sudden surge of electricity to shut down the whole $1000 equipment.

3.3.3 Voltage Regulator

A voltage regulator is a great device to stabilize the voltage sent to the appliance. Using a voltage regulator will not only help with measuring stable data but it will also help insure that the appliance perform at their optimum voltage level. Eliminating voltage fluctuation helps insure that our measurements are accurate and that the appliance using this voltage gets a steady flow of voltage.

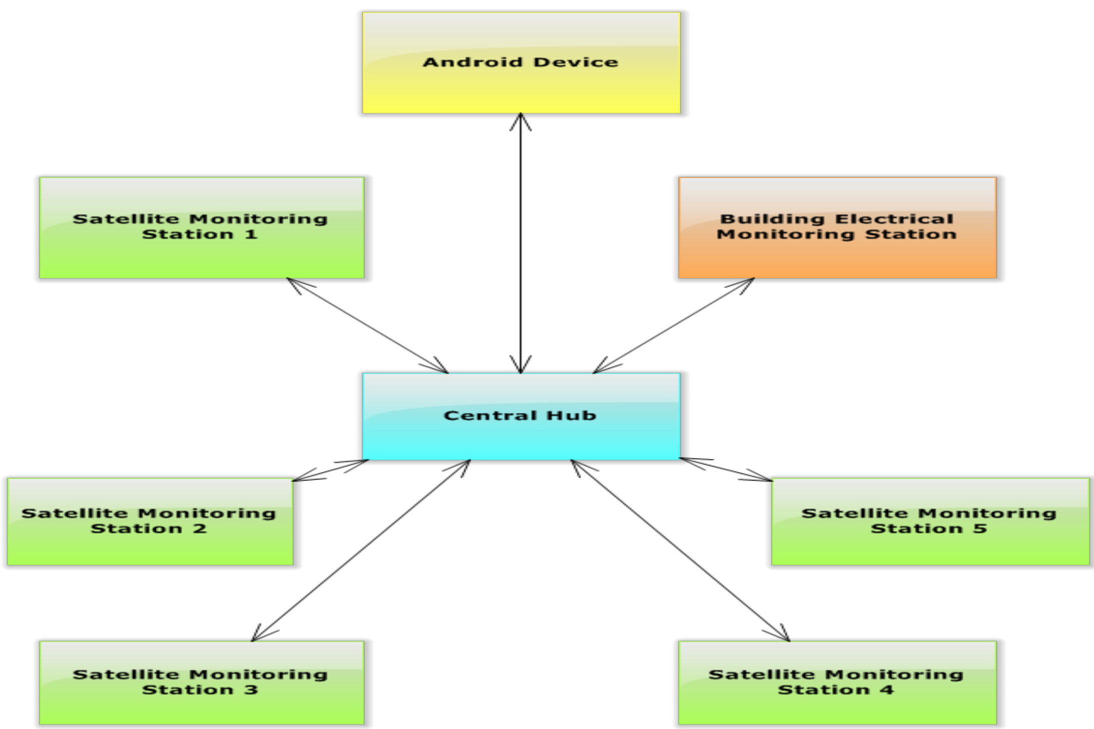
3.4 Possible Architectures and Related Diagrams

For our design we had in mind of using 5 satellite monitoring station that will look similar to the P4400 Kill a Watt but without the display, we are to include a current meter and a voltage meter inside this satellite monitoring station as well as a relay and a surge protector, an input power line that will hook up to the common house outlet and an outlet that will allow the user to connect the appliances to the monitoring station. If possible we hope that this will look like a wall plug that the device will connect to instead of a wire running to the wall then another wire running to the device which looks a lot more unprofessional. We will also include a Bluetooth device inside each satellite monitoring station as well as the central HUB and possibly a main electric cable monitoring station that will connect to the main electric cable coming into the house. The Main Electricity Cable Monitoring station will be unique as it will use the current transformer current sensor with the burden resistor to measure the amount of current flowing through the wire and the voltage. All of the satellite monitoring station will have a microcontroller to rework the data and calculate the power before this data is sent to the central HUB. All satellite monitoring stations and the central HUB will also have the Bluetooth device to transmit the data to the central HUB. To make sure the device is working properly we will include LED lights to check what part of the process is working and what could go wrong during the building phase. The central HUB will be the center of the information and will be capable of sending this information to either an android mobile device or a personal computer or simply displaying it on the LCD touch screen display. We will use an open source programming language to design and write the code for the software. The central HUB will also be equipped with the surge protector, as well as the Bluetooth device, and the LCD display, and possibly an emergency battery supply, a microcontroller, and a memory device possibly a flash drive. The input from the LCD will also have to get sent into the microcontroller and worked out what the user wants. We need to design a user interface and create the coding for operating the device as well as trying to make it user friendly while having optimized performance.

3.4.1Primary Architecture design stage

The Primary Architecture diagram is to show the bigger picture of our project. The idea is to have 5 Satellite Monitoring Stations communicating back and forth with the Central Hub and having the Main electricity cable Monitoring station to communicate as well with the Central HUB. What is hard to show on this diagram is the communication between the Satellite Monitoring Station themselves and between all of the satellite monitoring station and the Main Electricity Cable Monitoring Station. This will create a network of devices doing checks on each other making sure that all systems are functioning properly.

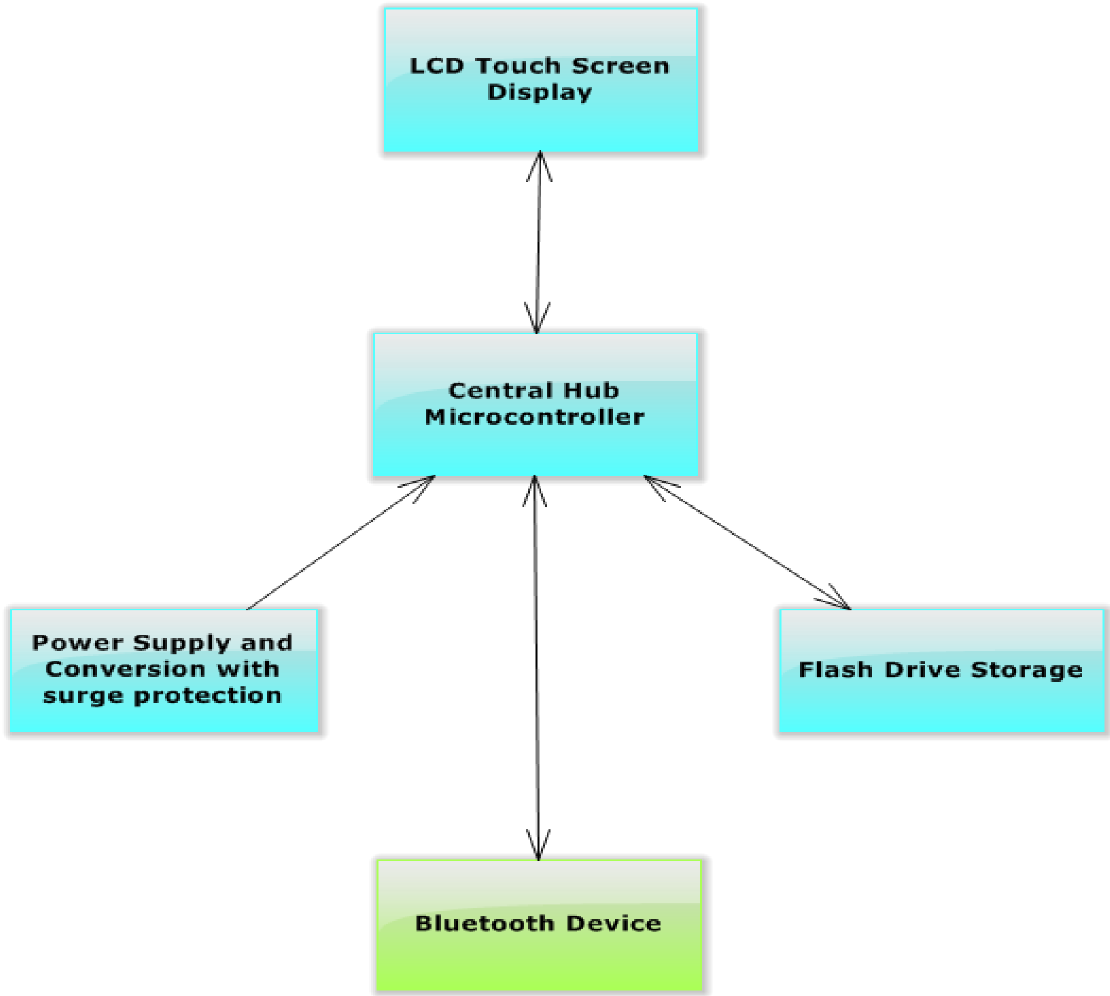
Figure 1: Primary Architecture Diagram



3.4.2 The Central Hub Diagram

The Central Hub will have the microcontroller, the Flash Drive to store the data, LCD Touch Screen Display to display the data, and the Bluetooth Device to communicate with the other stations, a personal computer, or a mobile Android device.

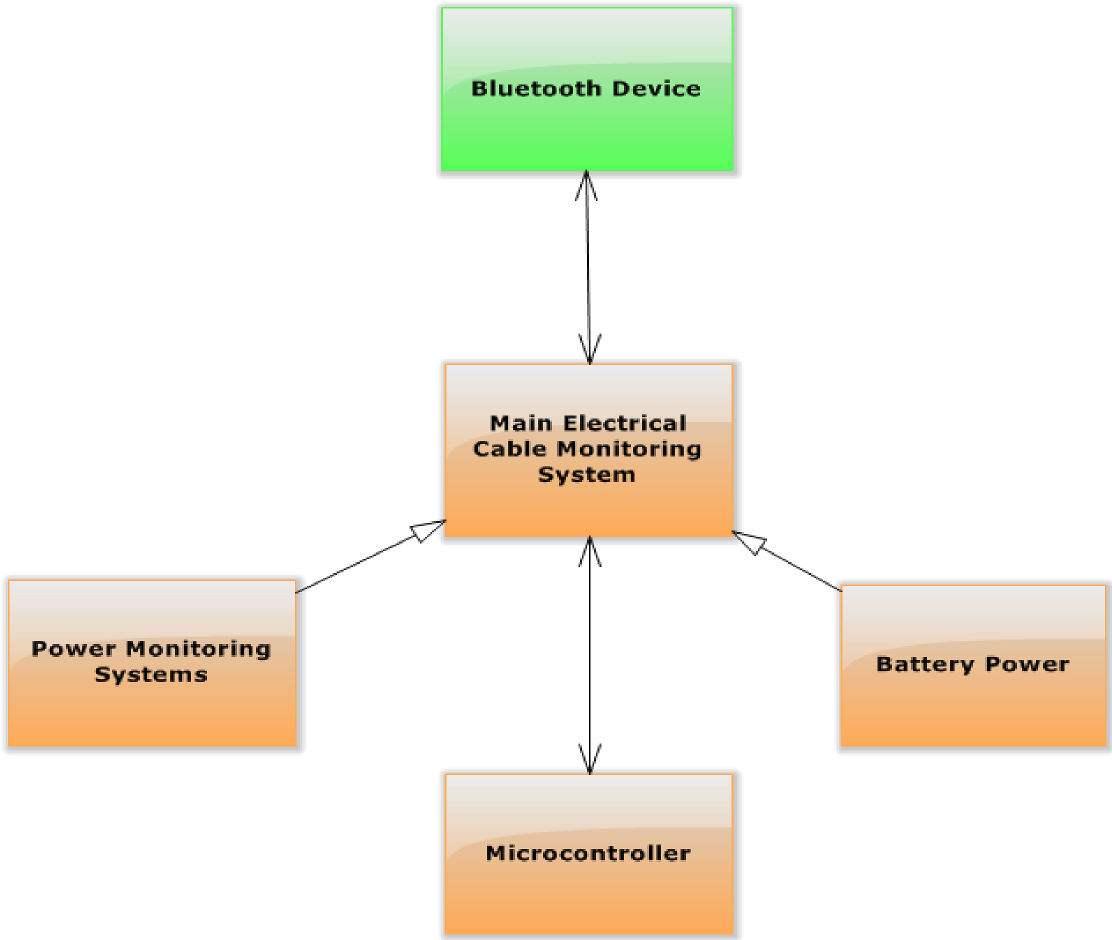
Figure 2: Central Hub Diagram



3.4.3The Main Electricity Cable Monitoring System

The Main Electricity Cable Monitoring System will monitor the power through the whole house and the idea is to power it using batteries. The Power monitoring system section contains the ac voltage meter and current meter that will be used to measure the current and voltage. The microcontroller will be used to work the data and the Bluetooth can then send the data to the Central Hub while also checking in on the other Satellite Monitoring Stations.

Figure 3: Main Electrical Cable Monitoring System Diagram



By using these diagrams we have an idea of what the final project will look like. All of the research done on different products and the idea we started with combined together and now we need to start looking at the specific parts that we are going to use in this project. After we have looked over the different similar technologies, there is not much left to do then accurately pinpointing what kind of technology we will need and what kind of technology we will add into each individual part of our device. One of the subsystems in our design is the microcontroller which was also part of the different products that we looked at but we did not discuss it yet. To get the whole idea of our device we would have to combine the different diagrams and give a summary of how these diagrams relate to one another and how they are connected with each other. The primary diagram shows how the users can interact with our device using a mobile device. He can also interact from the LCD screen which can be seen on the central hub diagram. Going back to the primary diagram we can see that the central hub will use the information given to it by either the mobile or the LCD touch screen to interact with the other satellite monitoring stations using the Bluetooth which can be seen in central HUB diagram and the Satellite Monitoring station diagram. Finally, the monitoring station upon receiving the information will process it using the microcontroller seen from the diagram to decide when and if it should cut off power to the appliance that is connected to it.

4.1 Satellite Monitoring Station

After further research we decided on a system that consists of four satellite monitoring stations able to gather data for residential, non-essential, continuous electrical loads. Each node is an individual device connected directly to the wall via a NEMA 5-15R plug and an input outlet for the device L5-30P that is interconnected with a wireless network for the transmission of data. The node or the satellite monitoring station is able to measure individual, single phase, resistive, inductive or capacitive loads.

The satellite monitoring station is one of the essential components of our system; it is where the basic, important data is obtained. Current and voltage are the basic components for the rest of the information provided to the user; from these measurements we will be able to calculate not only power but its components and finally the power factor.

The features for the satellite monitoring station along with its basic components are:

AC-DC isolated power supply
We will supply power to the satellite monitoring station by using small amounts of energy in addition to be able to choose between types of power depending on the load attached to the satellite monitoring station.

Surge protector
This will protect the satellite monitoring station from voltage spikes. The power lines in the distribution of energy provided by the utility could sometimes carry sudden spike increases in the voltage that last a few milliseconds. A surge protector component could protect it from this failure by using a clamping voltage. Also the surge protector will add robustness to the system.

EMI protection
The utility company power lines can sometimes carry noise and harmonics that could potentially harm the device connected to the satellite monitoring station, this issue could be greatly diminished by using appropriate filters and controllers that could potentially improve the noise immunity; a power factor correction is added to increase the changes of reducing the noise and harmonics.

Sensor circuitry
A device that will be sampling the continuous current and voltage signals in order to calculate the power consumption. These samples must be scaled down by using signal conditioning.

ADC
Converts the data received in analog to a digital signal with appropriate resolution, linearity and accuracy.

Wireless transceiver
The wireless transceiver will transmit data between the satellite monitoring station and the central HUB effectively, and efficiently using low energy per data transmitted.

Remote switch on/off
A remote switch will allow the user to control the power on/off provided to the device. This switch could be regulated in a time delay fashion, by setting a minimum operating voltage or by manually turning it off using a wireless device.

Indicators
Indicators will show the mode of operation of the satellite monitoring station by using different colored LEDs.

4.1.1 Features

The satellite monitoring station shall be able to perform the following:
1. be able to take an input of 120V AC +/-5%
2. Output within a range of 3.3V +/- 5% with a minimum efficiency of 85%
3. Sense voltage spikes in the range of 150 and provide protection against it via energy absorption at a minimum of 4300 J.
4. Collect voltage and current measurements
5. Transmit data wirelessly at an average distance of 10 meters
6. Remotely switch the power on the attached device on and off automatically and manually.

4.1.2 Specifications of the Satellite Monitoring Station

Table 6: Power Input

Voltage	120VAC
Phase	Single Phase
Frequency	60 Hz
Max Current	30 amperes
Max Load	2.88 KVA
Connection	L5-30P with rear panel
Monitors	NONE
Outlets	(2) 5-15R, 120V
P Protection	Spike/Surge
EMI filter	yes
OCP	No

Table 7: Sensors

Temperature	No
Humidity	No
Interlocks	No
Current	Yes
Voltage	Yes

Table 8: Communication Interfaces

Display	No
Serial	No
Wireless	Yes
Protocols	Bluetooth
Memory	SDS card

Table 9: Physical

Layout	Handle
Dimensions	5 1/2 “, 2”, 4 ½”
Weight	16 oz.
Finishes	Chassis: Plastic

Table 10: Operating Conditions

Temperature	32° to 122° Fahrenheit
Humidity	5% to 85% Relative Humidity
Elevation	6000 feet

4.1.3 Components

AC-DC Isolated power supply

The satellite monitoring station circuitry needs to be powered in two ways. One using AC voltage from the outlet and the other one by using double A batteries only to be a source of energy when there is a power outage. This emergency source will provide the necessary energy to save data acquire during the outage, be able to shut off the device plug into the node completely and send a notification to the user of the situation.

The state of operation of the satellite monitoring station at an AC signal has an incoming voltage of around 120 V from the outlet; this voltage needs to be stepped down to 12V RMS for the circuitry use just after it has been provided with the necessary protection from voltage spikes. The satellite monitoring station circuitry operates with DC therefore the step down AC needs to be converted to DC.

Another way to manage power is by the use of a transformer, in our case we would need a step down transformer with a ratio of 10:1 and able to take in 120V from the outlet, but this type of part is not easy to find and it would require components like a rectifier to convert AC to DC and additional components that would occupy space, dissipate heat and consume small amounts of power individually but collectively will add up.

Another specific way to convert AC coming out of the outlet to a regulated DC output is by using an AC/DC that is able to take inputs from 85V to 265 V AC, the typical PFC for an isolated AC/DC.

Within converters they are different types like: Boost, Buck, LDO (Low dropout regulator), CCFL backlight, Charge Pump and SVS/RTC. After this analysis we concluded that a Buck converter is suitable for our design since it steps down the voltage with 95% efficiency, it could convert the voltage from 12V to 0.8-1.8V for a microcontroller.

The surge protection will be added to prevent any damages to the device and the satellite monitoring station from voltage spikes, also this will help as later explain to reduce startup transient. One additional benefit from the transformer is the electrical isolation between the primary and the secondary windings against high voltage values coming from the outlet, providing an extra protection for the user when handling the unit.

A rectifier is added at the secondary winding, to start the process of converting the AC signal to a DC signal, between the two types of rectification: half wave and full wave, we chose the full wave because it produces less ripple voltage than the former, less filtering is needed to eliminate harmonics and it provides a constant polarity, we only need a positive output voltage for our measurements. Among full wave rectifiers, the bridge configuration is our best candidate requiring less turn in the secondary winding of the transformer and when we connect it to it we will get a decent output voltage. Also we will end up with 1ph2w22p per cycle doubling the sampling from the center tap rectifier. Another advantage of the full wave bridge rectifier over the center tap transformer is cost. The disadvantage with this type of rectifier is that when the current passes through two of the diodes, the output voltage end up as two voltage drop (2x0.7=1.4V). The ripple frequency also doubles. This problem will be later overcome by another component. One final stage includes the voltage regulator and a decoupling (bypass) capacitor(s). The voltage regulator reduces the noise and ripple voltage providing a steady direct current. Between the two main choices for a voltage regulator: linear regulator or switching regulator, we chose the linear for the following advantages taken from table 11 (taken from AN-556 introduction to power supplies/Texas instruments website): Excellent linear and load regulations, low output ripple and a fat transient recovery time needed for our design, the disadvantages like low efficiency, and small input voltage range could be compensated by other circuitry components included in our design.

As seen in table 11 the output voltage ripple of the linear type power supply is smaller than the switcher type power supply but the efficiency in switching is higher. Another advantage of the switcher is that there will be less power dissipated and therefore consumed. In addition, their physical dimensions are smaller and lighter when compare to their linear counter parts. Many times, switching regulators are used as replacements for linear regulators when these requirements are necessary in the design. Switchers have the disadvantage of being more complicated and could cause electrical noise problems.

A decoupling capacitor will be connected between the power supply and the ground; we will use a couple at different values to filter noise and to even out fluctuations in voltage when we connect a load that changes its power requirements.

Table 11: Linear vs. Switching Power Supplies[vi]

Specification	Linear	Switcher
Line regulation	0.02%-0.05%	0.05%-0.1%
Load regulation	0.02%-0.1%	0.1%-1.0%
Output ripple	0.5 mV-2mV RMS	10mV-100mVp.p
Input voltage range	+/- 10 %	+/-20%
Efficiency	40%-55%	60%-95%
Power Density	0.5 W/cu in	2W-10W/cu in
Transient Recovery	50us	300us
Hold up time	2ms	34ms

Surge Protector

Some of today's choices in surge protection are: the Gas arrestor, suppressor and varistors.

Gas arrestors are gas filled capacitors (most of the time the gas is neon) able to suppress overvoltage above 100V. They absorb high level transients and their leakage currents are very low but are not suitable for our design that requires a surge protector with a fast reaction time.

Suppressor diodes have a 5% tolerance and lower impedance than an MOV. Their clamping voltage comes close to 186V and their power dissipation is limited to their shape, but their current handling capabilities are lower than the MOV**.** According to NEC, if a load in a transformer exceeds 125% of its continuous current per phase (1 phase in our case) the circuit has to open.

In the 70 and 80's there were various varistors commonly used: silicon, selenium, silicon-carbide and the metal oxide types. The most popular one today is the metal oxide varistor commonly known as MOV which offer many advantages such as nanosecond switching speeds (typically 25ns), small size(within 5mm) and large currents suppression values (from the low 1200 up to 6500 amperes). The MOV is helpful in our design in many other ways, for example in very low voltages it acts as an open circuit thanks to its two phase materials (acting as an insulator). In the other hand, when the voltage reach the clamping level it acts as a short circuit protecting against surges. Also, the MOV requires very low power ranging from a few mill watts to 1 watt. For our design it will be very important to choose our MOV with a power of dissipation as low as possible to keep saving energy throughout the entire system. The peak operating voltage should be as close to the normal AC line voltage or even higher. The energy of absorption is another aspect of the MOV that should be taken in consideration as well as recurring and clamping voltage and energy level. The selection criteria for the MOV were based on table 12 taken from the Bourns electronics product line website.

Table 12: Metal Oxide Varistors Comparison Chart[vii]

Part number	MOV-07DxxxK	MOV-10DxxxK	MOV-14DxxxK	MOV-20xxxK
Varistor voltage	18V-820V	18V-820V	18V-1800V	18V-1800V
Varistor voltage tolerance	+/- 10%	+/-10%	+/-10%	+/-10%
Maximum continuous Voltage (Vrms)	11V-510V	11V-510V	11V-1100V	11V-1100V
Maximum continuous Voltage (Vdc)	14V-675V	14V-675V	14V-1465V	14V-1465V
Rated wattage	0.25W	0.40W	0.60W	1.00W
Max. Response time	25ns	25ns	25ns	25ns

EMI protection

We would like our design to be free of electromagnetic interference and immune of possible outside disturbance. Common ways to minimize these interference and disturbance are line filtering, power supply design layout and using a shielding enclosure. Rather than electrical interference transmitted through the power lines we are more concern about malfunction of the hardware, data distortion due to a disruption in the sequence of the microcontroller algorithm and signal distortion due to a poor layout design of the system. We will take care of the later by making sure we have an effective, simple system design but we will like to include an additional component that we will ensure a quality data incoming and outgoing of the entire design.

We will consider certain criteria when adding a filter that will provide EMI protection. First, the filter should provide attenuation of EMI device; it shall be place close to the AC input of the system, before the transformer of the AC/DC power supply, with its ground connections as short as possible to reduce inductance and impedance.

Some of the possible components that could be used as an EMI protector are: ESD structures, capacitors, series resistors, chokes and ferrites. Due to space constraints we chose to use an ESD structure for our design. During our research we found the following ESD structures as the best candidates:

IP4285CZ6-TD ESD protection for high speed interfaces from NXP semiconductors
TPD2E1B06 Dual channel high speed ESD protection from Texas Instruments
ESDsV3Uxx Ultralow capacitance series TVS diodes from Infineon

All of them are compliant with the minimum requirements of IEC61000-4-2 standards 8kV for contact discharge and 15kV for air discharge protecting sensitive electronics connected to communication lines. It also has an operating voltage between 3.3V to 5.3 V, Ippmax in the nano-range and a parasitic capacitance less than 4pF. We chose for this device the ultralow capacitance ESDsV3U4U02LS with an ultralow capacitance between

0.4-0.45pF, operating voltage 3.3V and an Ippmax 3nA useful for high speed interfaces with baud rates of 8GBd. We would like to use this ESD not only to protect the circuitry from static but to specifically protect the Bluetooth device in our system.

Complying with regulations in electronic devices

Is important to note that residential, commercial and everywhere else inhabit by the public is subject to governmental regulations to ensure the safety of the occupants. We will like to mention some of the relevant codes to our design.

IEC 61000-4 Standardized test methods
IEC 61000-4-2 Test for electrostatic discharge (ESD)
IEC 61000-4-4 Test for transients (FTB)
IEC 61000-4-5 Test for High Energy transients (SURGE protection)
These tests are based on realistic models for electrical noise.

Sensor circuitry

The power supply through the wall outlet is delivered in a sinusoidal form with a frequency of 60 Hz. In this part of the satellite monitoring station we must gather current and voltage data at a sampling rate twice the original frequency (120 Hz). They are different ways to monitor, sensor or measure the current and voltage values necessary to calculate power magnitude and power factor. First, we have two main options: to measure in AC or DC. Measuring in AC is direct but not simple. In an AC signal we have a sinusoidal waveform with infinite number of values which from we would end up with a large amount of samples that need to be integrated to get to an accurate value for our voltage. Another disadvantage for our design if we were to choose to measure directly at the AC level is the type of component necessary to measure both voltage and current. During our research the most commonly used methods to measure voltage are large bulky components, example: the AC/DC adapter. If we decide to use a Current-to Voltage Conversion by using a Hall Effect Sensor or a Low impedance resistor used in series with the load, this will carry a more complex and bigger design that will also increase the power consumption of the device itself. Also we would have to carefully measure current and voltage simultaneously to avoid any phase shift, attracting more harmonics to the system and complicating the design even more.

There are different types of sensors using DC signal: precision Voltage sensors, current shunt monitors, current sense amplifiers, magnetic current sensors.

Precision voltage sensor

The precision voltage sensor uses low power and dissipates very low energy and heat. It measures both in DC and AC.

A voltage sensor measures the differential voltage between the input terminals and outputs the difference proportionally. The maximum differential voltage that can be measured accurately is +/- 30V.
Features:

4.1.4 Current measurement

They are different ways to measure current, when making a formal decision we as a group should take in consideration the following: The magnitude of current, the need for galvanic isolation, accuracy, response time and simplicity of the design.

Current sensor amplifiers, typical current transformer, magneto resistive current sensors, Hall Effect current sensors, and others are typical examples of current measuring techniques. Below table 13 summarizes the basic measuring techniques: Resistive, optically isolated and magnetic.

Table 13: Common Current Measuring Techniques[viii]

Type	Current Range	Isolated	Accuracy	AC Response	Non-intrusive	Cost
Resistive	Very Low/ High	No	High	Medium/ High	No	Low
Optically Isolated resistive	Medium/ High	Yes	Low/ Medium	Low/ Medium	No	Low/ Medium
Magnetic	Medium/ Very High	Yes	Medium	Medium/ High	Yes	High

For the purpose of our design the systems should be able to measure currents in the range of 0 to 25 amps; this is the typical range for electronic devices at home. Also the current sensor needs to be isolated for safety purposes, and accuracy and to be able to transmit reliable data, and with a fast response time.

The optically isolated resistive method provides isolation but the voltage necessary to drive the device is not so small. As a consequence, the power dissipated trough the resistor is more than necessary using most of the providing power to run the entire circuit. Also the resistor dissipates heat, increasing the temperature in the circuit and increasing the current. If the resistance is vastly reduced the resulting circuit will end up with a low offset voltage compromising the accuracy of the system.

The magnetic current sensor is isolated offering safety, but unlike the optically isolated resistive method it does not require a sensor resistor that dissipates relatively high amounts of power. This method can only be used in AC systems instead of DC systems.
The resistive method offers very low current range, is not isolated but it is low cost, high accuracy and a medium to high AC response.

A brief description of commonly used sensor that use these technologies:

Current Shunt Monitor

They are accurate in their measurements thanks to the gain provided by the strategic placement of the resistors; they could be used at the low and high side and support common voltage between -22V to and 80V. They are easier to be implemented in a design with a low cost and low noise.

Current Sense Amplifier
They could be powered using low voltages. The resistive element is small providing a low dissipated power in a small package at a reduce cost.

Magnetic current sensor
Large bandwidth allows a wide range of current measurements. They might use non-contact current sensor allowing isolation. Small size and high sensitivity makes them a great choice.

For our design we are interested in a similar approach to the resistive current sensor. Additionally after searching for a way to integrate all the possible components necessary to carry an efficient measuring circuitry like sensors, voltage dividers and ADC, we came across a sensor that included all of this device in a single convenient package that will save in terms of cost and space in our design: A current shunt monitor. Among our choices the current shunt monitors: LMP92064 Simultaneous sampling current sensor/voltage monitor sensor, INA 226 High low sensing measurement sensor or the INA 210 Equivalent to the INA 226 but includes a zero drift.

When comparing these current shunt monitors the ADC characteristics are taken in considerations and three main identifiers are: input voltage range, resolution and bandwidth (conversion rate)

LMP92064 (TI)
Simultaneous sampling current sensor/voltage monitor sensor
Provides two simultaneous sampling 12 bit ADCs at a conversion rate of 125KSps (min) using a current sense channel. This is a digital current and voltage sensor with a digital SPI interface. It includes a shunt resistor and a buffered current channel to measure the load current and the load voltage respectively. These are sampled simultaneously.

INA 226 High low measurement, Bi-directional current monitor with IC2 interface
It measures both voltage drop and bus supply voltage by using a current shunt. The calibration, conversion times and averaging are programmable using 16 addresses. It draws a small current of 300µA.

LMP8481 Precision 76V High-Side Current Sense Amplifier with Voltage Output
This precision sensor has both bi-directional and uni-directional sensing, gain accuracy +/- 0.1%, common mode voltage range 4.0V to 76 V, Supply voltage range 4.5V to 76V, bandwidth 270 kHz. Because the operating voltage supply overlaps with the common mode voltage range this device could be powered by the same device it is measuring.
Our choice is the INA 226 it provides a great accuracy: 0.1% gain error; a desired ADC resolution: 16 bits; a maximum conversion time of 9ms and a power supply within the range of our power supply: 3.3V. A brief explanation on how to determine the necessary resolution is explained in the energy measuring process section.

4.1.4.1 Energy monitoring: Using a current shunt monitor

The current shunt monitor measures current and voltage by measuring the differential voltage between pin VIN+ and VIN-, and the voltage bus going in VBUS pin. The value of the shunt resistor and the resolution of the current register most are program to be able to apply the differential voltage. These values are use in the calibration register to get to the values of current and power. The Current_LSB is responsible to set the current to amps. Using the smallest number round off in the Current_LSB register. If the Calibration Register is not programmed the power and current register will remain at 0.

CAL= (0.00512)/ (Current_LSB*Rshunt)

Current_LSB=Maximum Expected Current/ (2^15)

(or active power), this is the one the electrical company uses to charge the monthly energy bill, and the one that is actually use for work by the device, therefore the most important in our project. Other components of power are the reactive power (or imaginary power), and the apparent power. The reactive power goes back and forward from the load to the mains, is not unidirectional, and the phase between the voltage and the current is 90 degrees, for the half of the cycle the power graph is positive and the other half cycle is negative, indicating that the energy is going to the load and coming back to the source.

Real Power (Active Power) watts (W)
Reactive Power (voltage-ampere reactive) (VAR)
Complex Power (voltage ampere) (VA)
Apparent Power is the magnitude of complex power (VA)
The relationships between these different components of Power are:

Real Power= Apparent Power x Cos (δ-β)

Reactive Power=Apparent Power x Sin (β-δ)

Cos (δ-β) is also known as the power factor. The phase angle (δ-β) is the angle between voltage and current and is called the power factor angle.

Calculating the Real Power:

Calculating the Real power is mainly multiplying the instantaneous current by the instantaneous voltage. The instantaneous current could be find out taking around 20 samples during a cycle then take the mean of this value, do the same for the instantaneous voltage to get to the mean of the voltage as well. Then this two data are taken by the microcontrollers and using the software calculates the Real Power.

Calculating the Apparent Power:

The apparent Power is the magnitude of the Complex power. The complex Power itself is the vector sum of the real power and the apparent power.

The way to calculate this apparent power is to use the RMS or *effective value* of the current and the RMS of the voltage using our instantaneous sample measurements.

Calculating the Power Factor:
Using the equation for power factor=apparent power/real power, program into the microcontroller we get to find out the power factor.

Resolution and conversion data rate
Most current sensors have an input/output in analog, but most wireless transceiver have a digital input pin making an analog to digital conversion necessary by using a converter. Except, our selection, the sensor INA 226 already has an internal ADC. Generally ADC's are characterized by their input voltage, resolution and conversion data rate. Out of these three, resolution is decisive factor when selecting some of our components like the sensors that includes an ADC. The resolution will determine the precision of the measurement and this value is also needed to determine which microcontroller we will be using.

Most of our devices including the current sensor and the power supply AC/DC conversion have an external voltage reference of 3.3V, but with an internal Voltage of 2.5 V. Using the internal voltage reference value 2.5V and the ADC inside the INA 226 current shunt monitor at 16 bit gave us a 0.038mV Voltage resolution, better than 0.610mV for 12 bits. The formula use for this calculation is: Vref/2^n.

The sampling rate or the conversion rate is another important element in transmission of data. If the input signal changes faster than the sampling rate the value of Vin obtain could potentially fall between counts resulting loses of data samples during the conversion process. According to the Nyquist Theorem the sampling rate has to be at least two samples per period, therefore the clock frequency has two be at least two times greater than the input frequency, in our design the input frequency or the frequency of the AC signal coming out of a household outlet is 60Hz giving us a minimum clock frequency of 120 Hz for sampling purposes. The current shunt monitor datasheet shows an internal ADC with a delta sigma front end 500 kHz (30%) typical sampling rate. This big gap between bandwidth could cause undesirable aliasing losing unrecoverable information. This situation could be corrected using signal conditioning and at the same time correct some of harmonics at this level (utilities could have up to 40). Using the INA 226 allows conversion times programming for the shunt voltage and a bus voltage simultaneously or at different time settings. The lowest setting time is every 140us or 8.244 ms. Another feature is to average the measurements but there are not as accurate this will have to be filter to improve the signal and improve the quality of the signal. The accuracy of the current sensor could be greatly improve by increasing the conversion time and at the same time have a high number of averages.

ADC Converter
The current shunt monitor includes an ADC converter simplifying the design; therefore in external ADC converter is unnecessary.

Wireless transceiver
The energy monitoring system is a design for an average American household; short distance wireless technologies are acceptable. We are choosing Bluetooth technology

that will require a transmitter and a receiver module. At the monitoring node we are placing the Bluetooth mate, a necessary device to send data wirelessly. They are several options in the market that are mostly compatible with Arduino microcontrollers. We are required to use a different brand of microcontroller besides Arduino, but we could adapt the microcontroller to work with these devices. RN-42 Bluetooth module and SMIRF are some of the selections. They have a range of 10 meters, transmission power of 2.4GHz in a band between 2402-2480 MHz. Conversion rates of 250Kbps that suite our current sensor specifications.

Remote switch on/off

One of the many features of the design is the ability to turn off/on the device connected (or load) wirelessly. They are three states in the device: on, off, or standby. Some electronic devices still consume small amounts of power when they are off if they are still plug in, this power is called standby power or phantom energy. In average every household has at least 40 electronics that will are constantly adding consume power, eventually making the electric bill higher.

They are several ways the power could be shut off completely in our design we will use remote power control, timing control, minimum voltage control and manual control. In the time control type, we will determine certain times of the day where the device will completely shut off. In the minimum voltage control type, when the measurements of voltage used fall below certain level, the actuator will shut of the device completely until is wirelessly activated. The last type of control, the user will shut off the device remotely by use of a cell phone.

This automated control is regularly use in many designs turning on and off, lights, air conditioners, and other appliances. This systems use light sensors, temperature sensors and others. We will like to show this concept application in electronics devices to reduce phantom energy in a household.

The relay is the type of electronic component that we will use in our design. Between the two types mostly used the mechanical relays and the Solid state relay, the former is a simpler and safer method to implement than other types of relay used, but this relays could get very bulky an inconvenience for our small project. The other types of relays that we could consider are: zero crossing silicon controlled rectifier (SCR), intelligent solid state contactor, SSC or solid state contactor, phase angle silicon controller rectifier (SCR), mosfet solid state relay, IGBT(insulated Gate bipolar transistor), Solid state relay and the opto-couple Triac. We chose the Solid state relay not only for it cost even though it was a risker alternative, if improperly place in the circuit it could cause some sparks, but it is the ideal switch for a circuit that does not required the movement of parts, just the control of power in a circuit; for example, the solid state relay switching time is in the microseconds to milliseconds, uses low current, low noise when switching, it operates silently, it is smaller than other types of relays and less sensitive to the environment (humidity and magnetic fields) also is relatively smaller than the SSC, SCR and IGBT. The Opto triac relay in the other hand does not need a complex circuitry but offer similar advantages to the SSR. A SSR has a great compatibility with control systems like PLC or with microcontrollers that allows networking.

When looking for a specific type of SSR besides dimensions, cost and power usage we look at the following points:

- The type of electrical environment, if it is harsh (potential high transients) then a SSR with rated voltage higher than the main operating line voltage of the design should be considered.
  In our case we consider the conditions to be harsh since we are using AC prone to transients in sensitive components.
- The current rating, they are RRS from 1 arm to 150arms, when choosing the rating making sure it usage do not exceed its 70% of its ratings. We probably use from 1 amp to 15 amps in our satellite monitoring node.
- Nominal AC line voltage: 120Vrms, 240Vrms, 380Vrms, 480Vrms, 600Vrms, always allowing for a higher voltage rating than normally used; Or the equivalent DC voltage 18-38 Vdc, 90-140 Vdc and 90-280Vdc. The voltage that we are using is 110~117V, with a step down to 9Vdc consequently a rating between 18Vdc-38Vdc is an optimal choice. (in the next paragraph we will explain why we decided to use DC instead of AC)
- The control voltage is in DC or AC and the range of the control voltage; typical Ac range are 18-36 Vrms, 90-140 Vrms and 90-280Vrms, in DC ranges are 3-15Vdc, 18-36Vdc, 90-140 Vdc and 90-280Vdc. In some type of relay the control voltage can get separated into two ranges. For our purpose of design the meter will have two ranges to allow control of the device and the meter itself. The usage of the device could range from 3-15Vdc and 18-36V.
- Is it normally open or normally closed RRS and some relay offer both options. We prefer the later.
- Operating and release time, necessary between changes of control signals a maximum of 16.67ms for 60Hz and 20 milliseconds for 50 Hz.

There is another classification of relays, if they use the AC or DC signal. We consider two important issues when dealing with AC relays, first, the coil temperature in an AC relay rises higher than in a DC relay (due to the eddy current losses, hysteresis loses and shading coil), second, chatter may occur and cause the part to burned out or interfere with the relay performance. Chatter could occur if a load with a motor could create a voltage drop, changing the relay’s turn off/on voltage. Instead for DC switching relays the temperature does not get as high as in the AC relay, the relay works when the voltage reaches the specific critical value, but it move slower, waiting for the coil to move at higher or lower dropout voltage with increase temperature. Another disadvantage with the DC relay is that when using inductive loads these one could potentially create EMI and at the end created damage to the contacts of the relay (this is due to the zero cross point unlike the AC relay).

We are more incline to use the DC relay, our most important concern is energy savings and with heat dissipation and therefore power dissipation we could not accomplish this goal with the AC relay. Certain components and circuits as well as measurements could be taken to diminish the disadvantage previously mention. For example, to avoid EMI as much as we can the relay could be place at a fair distance from a component causing electromagnetic fields like a transformer does. Also, the EMI protection could be place near the relay to protect it from possible electromagnetic interference.

A variety of relays exist depending on the functionality of the internal coil, example: Single side stable relays, Single coil latching relays, Dual coil latching relays, some of them integrate diodes in parallel to protect the coil from EMI, other have a built in operation indicators for immediate check of the relay operating status. Since the switch for our project has to stay on or off until the program orders otherwise, we decided that the dual coil, latching relay offers a coil that set and reset retaining the status. The relay material could exhibit arc resistance even a high melting point, good alloys that offer this characteristics are AgNi and AgW.

For our ideal relay our desirable characteristics include:
Dual coil-Latching-Built in diode-Built in operation indicator-AgNi or AgW-DC

Some of the relays that we consider for our switch ON/OFF device are:
SSR LC241R from crydom, a zero cross type/triac output SSR S216S02 from Sharp, SSR Z3314-ND from Omron Electronics.

It was hard to find a relay that met all of the ideal characteristics previously mention, the RT424F24 RT2 Bistable (TE connectivity) met most of the requirements at a reasonable price $5.69.

Figure 4: Satellite Monitoring Node Components Diagram

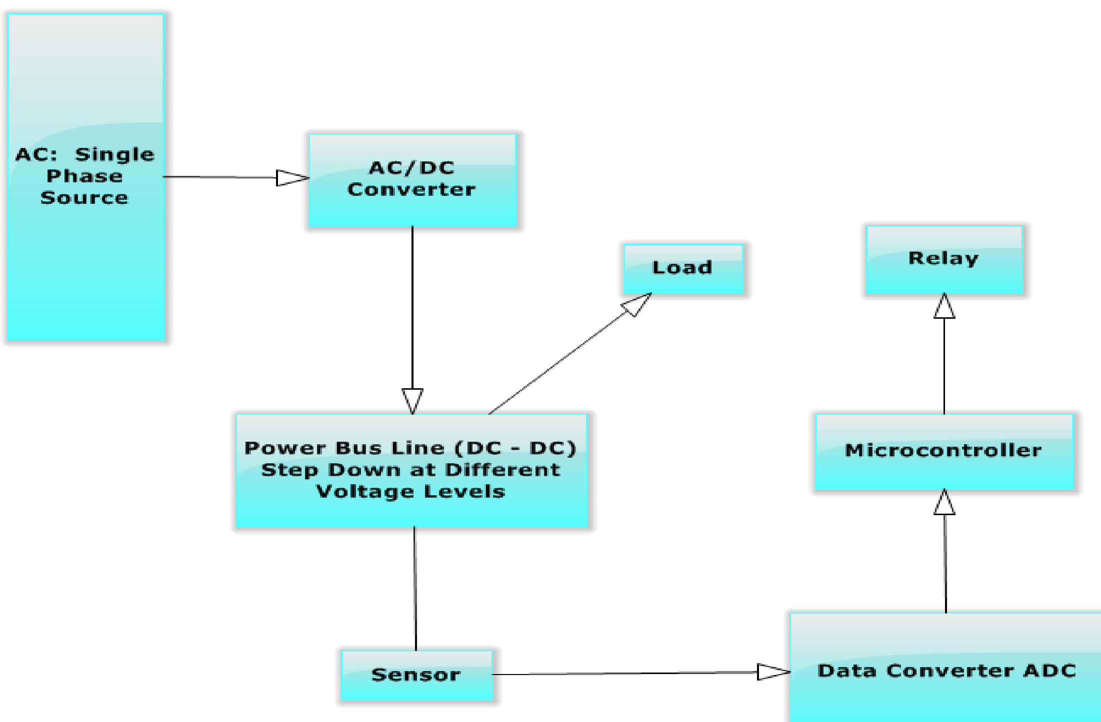


Table 14: Considered Relays:

Part Number	**G5RL-1A-E-HR-DC**	**RT424F24**	**DK1A-L2-12V-F**
Series	G5RL	RT2 Bistable	DK
Manufacturer	Omron Electronics	TE Connectivity	Panasonic
Purpose	General purpose	General Purpose	General Purpose
Type	Non-latching	Latching, Dual coil	Latching, Dual coil
Material	Ag alloy	AgNi	AgSnO
Mount type	Through Hole	Through Hole	Through Hole
Coil current	16.7mA	16.7mA	16.7mA
Coil voltage	24 VDC	24VDC	12VDC
Coil Power	400mW	650mW	200mW
Coil resistance	1.44kΩ	886Ω	320Ω
Switching voltage	250VAC, 24VDC max	400VAC max	250VAC/12.5VDC max
Contact rating	16A	8A	10A
Turn on voltage (max)	16.8VDC	16.8VDC	8.4VDC
Turn on voltage (min)	2.4VDC	----	-----
Operating Time	15ms	10ms	10ms
Release Time	5ms	5ms	8ms
Temperature (op)	-40°Cto85°C	-40°Cto85°C	-40°Cto65°C
Cost	$3.48	$5.69	$11.61

4.1.5 Signal Conditioning

The measurement of current and voltage would probably include noise and other interference like harmonics.) is recommended by the manufacturer (TI) to use a filter at the front end of the input pin for the INA226. The large bandwidth allows the use of small resistors (10 Ω) and capacitors (0.1μF) that will not affect the accuracy of the measurements. Inductive and transient voltages are prevented by the use of the MOV and ESD is taken care off with EMI devices previously describe. The filter in front of the input pin of the current shunt reduces any aliasing of the signals.

4.2 Power Supply

As discussed before the design will be using DC across its power supply instead of AC, mainly to reduce heat and power dissipation saving more energy. Amount the different ways to step down the voltage coming out of the outlet; it has been mentioned the transformer. Several converters are in the market today, with different classifications and features. The first one to consider it the type of mode the power supply is using switching or linear. Switching converters the main power to a load by changing the voltage and current characteristics. The switching supply constantly switches from low dissipation to high but it does not stay too long on the high dissipation. In the Ideal world the switching device does not dissipates power unlike a linear power supply that is constantly dissipating power in the pass transistor. Another advantage of a switching power supply over a linear one is physical dimensions. Switching power supplies most of the time are smaller and lighter saving Board Real Estate. Switching regulators are generally used when higher efficiency, smaller size and lighter weight is necessary for the design. In our project the satellite monitoring node is not design to withhold too much weight or space of parts; therefore we were always looking for an affordable way to provide components that agree with these characteristics. They are, however, more complicated; their switching currents can cause electrical noise problems if not carefully suppressed.

A list of specifications of Linear vs. switching power supplies are presented at table 15 (taken from AN-556 introduction to power supplies/Texas instruments website): Excellent linear and load regulations, low output ripple and a fat transient recovery time needed for our design, the disadvantages like low efficiency, and small input voltage range could be compensated by other circuitry components included in our design.

Table 15: Linear vs. Switching Power Supplies

Specification	Linear	Switcher
Line regulation	0.02%-0.05%	0.05%-0.1%
Load regulation	0.02%-0.1%	0.1%-1.0%
Output ripple	0.5 mV-2mV RMS	10mV-100mVp.p
Input voltage range	+/- 10 %	+/-20%
Efficiency	40%-55%	60%-95%
Power Density	0.5 W/cu in	2W-10W/cu in
Transient Recovery	50us	300us
Hold up time	2ms	34ms

As seen in table 15 the output voltage ripple of the linear type power supply is smaller than the switcher type power supply but the efficiency in switching is higher especially when the Vout and Vin difference is high. Another advantage of the switcher is less power dissipated and therefore consumption in addition their physical dimensions are smaller and lighter when compare to their linear contra parts, many times switching regulators are used as replacements for linear regulators when this requirements are necessary in the design. Switchers have the disadvantage of being more complicated and could cause electrical noise problems. This noise problem could be fixed by using decoupling capacitors.

When choosing power supplies also should be taken in consideration the existence of isolation. There are Isolated and non-isolated converters and regulators. Isolated devices have no DC current flow between input and output, a transformer couple’s energy from primary to secondary thru magnetic field. In contrast, a non-isolated version has a DC path between its connections.

Non-isolated converters have a much simpler design than an isolated converter. Isolated power supplies usually include transformers and optical isolators. Mostly power supplies use for computers and related loads, use a fully isolated device from the mains. Optical isolation is used for feedback and transformers for galvanic isolation. It is very important for this type of loads to be fully isolated because a main supply could be unpredictable and go out of the range of their nominal specification.

DC-DC converters are generally in the form of 5V, 28V, 48V since this voltages are low, and isolation is not fully required. Therefore in our design we will focus in using non-isolating power supply elements.

Different power supply topologies for DC-DC converters

They are many different power supply topologies and within the DC-DC converters. Each topology has specific features that make them best for determine applications. Different types of topologies includes: Boost, Buck, Buck-Boost, LDO (Low dropout regulator), Charge Pump and others.

The buck regulator or step-down regulator is the simplest of all the topologies, as the name implies this regulator reduces the output voltage to a bus voltage usually 5V to power a TTL logic. Therefore, the buck converter always produces a lower output. In the buck converter, a switch is in series with the input voltage source. When the switch is ON in a steady state operation, the input provides energy to both the internal inductor and the output. The inductor current is continuous and it never reaches zero during a cycle. In this case the buck converter is also known for a continuous conduction mode. The Equation that gives the relation between input voltage and output voltage:

Vout=D*(VIN)
D=Ton/Ts
Ton=ON Period
Ts= Switch Period
The Boost regulator is another type of regulator capable of increasing the input voltage. Some of them increase a 5V to a 12 V. The main functional concept as the buck regulator applies here in reverse. An inductor is placed in series with the input voltage. The input voltage provides energy to the inductor when the switch is ON. The current through the inductor never reaches zero in one cycle in fact is a continuous mode. The boost regulator is also known as Continuous Conduction Mode.

Buck-Boost converter is another type of converter where the output voltage could be either greater or less than the input voltage magnitude. Within the buck-boost converters there are other two interesting topologies, the inverting topology and the Buck followed by the Boost. In the inverting topology the output voltage is the inverted polarity of the input voltage. The output voltage could be adjusted with the duty cycle of the switching transistor. In the buck followed by the boost the output voltage is the same polarity than the input, but lower or higher.

The LDO or low dropout is a linear voltage regulator that operates in a very small input-output differential voltage, its advantages are low minimum voltage, high efficiency and low heat dissipation. It has a power control inverter function that requires another inverting amplifier to control it, this raises the complexity of the design related with this type of regulator.

Charge Pumps voltage regulators are inductor-less reducing noise at the input and output level instead they use capacitor as energy storage elements. They could be used as step up or step down and/or invert the input voltage and it could double the voltage output. They provide great efficiencies as high as 90to95%.

Selection of the right topology

To select the right topology for the design is important to know the basics of the operation of the design as well as it complexity; also important is where the topology will be use. Some factors that could help in the decision of an appropriate topology are:

Is the desired output voltage higher or lower than the input voltage?
How many outputs will be needed?
Is any isolation necessary?
Is the input/output voltage high?
Is the input/output current high?
What is the maximum duty cycle?

Out of these questions we could determine if we need a buck, boost or other type of converter. In our case we require a step down of the voltage therefore, a buck regulator or charge pump could be between our choices. If isolation is necessary or not and how high the voltage is will determine if a transformer is necessary, in the design we will direct the output to low voltages therefore isolation is not necessary. Reliability is determined by the maximum duty cycle.

In addition to these topologies other types of power supply components are helpful in the design of the circuitry for example a power module. A power module is a physical containment for several components that could be connected to an outer circuit; examples are a switch, half bridge (inverter), and 3 phase inverter.

For the design the best option is a non-isolated step down (buck) module (converter). One of the parts that has all the requirements is the PTH12050W 12V, 6A Module. It is one of the smallest in its series, simplifies the circuitry of the supply voltage by enabling modules to track external voltages when there is a power down or power up. Below table 16 describes the parametric for this part.

Table 16: Parametrics PTH12050W

Manufacturer	TI
Regulated Outputs (#)	1
Vin(min)(V)	10.8
Vin(max)(V)	13.2
Iout(max)(A)	6
Soft Start	Fixed
Vout(min)(V)	1.2
Vout(max)(V)	5.5
Special Features	Enable, Output, Discharge, Tracking
Topology	Buck
Approx. Price	$6.90
Operating Temp.	-40°Cto85°C

4.3 The LCD Display

4.3.1 Touch Screen interface description:

The screen interface or LED will have the main information for the users to understand and interpret. The main screen needs to be very specific, but user friendly at the same time. It is not desirable an interface difficult to understand by the users because it will lose interest from the targeted people to the device. The main parts of the screen interface are:

- Consumption of power
- Consumption of power in terms of money and how much is saving
- Phantom Power consumed
- Functions
- On and Off

For this project, the LCD Display or Touch Screen Interface is a very important part because it is the interaction between the user and the system. There are different types of LCD Displays to choose from. It is important to define them, compare them, and decide very wisely which one is the best for this project.

4.3.2 Types of Touch Screen Interfaces:

4.3.2.1 Resistive Touch Screen:

A resistive touch screen consists of different layers, one over the other. When the user presses the outer layer, it also touches the inner layer. When these two layers are in contact, a current run between then in the same exact spot where the user pressed. This is an equivalent of a click button in the computer mouse doing the exact same function. The downside of this technology is that the users need to press the screen a little bit harder than when using other types of touch screens.

4.3.2.2 Capacitive Touch Screen:
A capacitive touch screen relies on the human electrical properties to detect when and where the screen is being touched. This touch screen uses layers of capacitive material that stores electrical charges in it. When the person touches the screen, these charges change in that exact point. Being designed in this form, it is more easily for the user to press the screen, not like the resistive touch screen that has to be pressed harder. With the capacitive touch screen, the images are clearer than with other technologies. The downside of this touch screen is that cannot be utilized with accessories like stylus pen or gloves.

4.3.2.3 Surface Acoustic Wave Touch Screen:
This technology is being slowly replaced by other technologies. It uses sound waves which are placed along the edges of the glass. Two transducers are placed in two corners and two receivers in the two opposite corners of the glass. When a sound wave (which travels parallels to the edges of the glass) finds a reflector the wave is transmitted from transducer to receiver. Exactly there is a touch point and the touch screens can amplitude the sound where the user touched. Some advantages are: high transmission and optical clarity, durable glass construction, and pressure sensitive. Disadvantages are: it is harder to integrate, is not as durable as others, it is vulnerable to water and other contaminants, needs to be calibrated constantly and the touch of the screen has to be very light and sensitive.

4.3.2.4 Infrared Grid Touch Screen:
This touch screen is integrated with printed circuit boards which have a line of LED's and transistors hidden in the touch screen. The LEDs and the transistors are located on opposite sides to create an invisible grid of infrared light. The controller of the Touch Screen pulses LEDs to create a grid of IR light beams. Then, when the user touches the screen, enters to the grid by interrupting the light beams. In this way, the transistors of the frame are able to detect exactly where the user just touched the screen by identifying X and Y axis. This one has a lot of advantages like: 100% light transmission, almost all kind of stylus can be used, and longer among others. But it is better used for ATMs, ticket machines, and large plasma displays.

4.4 LCD Display Chosen

The Touch Screen Interface chosen was resistive technology. The reason for that is that, even though the performance is not as good as the capacitive, it is very useful for the specific tasks that the device will be performing and it is extremely cost effective (very cheap compared to capacitive touch screens). In addition, the resistive touch screen is being used for very important devices today. There are a lot of different LCD displays to choose from, but the main criterion for the device was: low power consumption, cost, interface complexity, size, features and type among others.

The first one to consider is the arLCD - 3.5". This LCD is very cost effective (only $90). It works with Arduino boards and it is very easy to integrate package. It uses EarthSMPL, which is a very simple embedded Macro Programming Language; this definitely will help on the integration of the LCD to S.H.E.M.S. This embedded language is also defined as a very easy API. This LCD include many images, widgets and sample macros like meter, buttons, checkbox, slider, and more that makes it even easier. This is a resistive touch screen, which is not the desirable interface, but the price is very convenient. Features of this LCD are:

- 6 - 9 V operating voltage
- Arduino Compatible
- 3.5" Color LCD
- 320 x 240 Resolution
- LCD Backlight
- 500:1 Contrast ratio
- 16 bit GPU
- 4MB Flash Memory
- USB mini-B cable

Another LCD considered is the Serial TFT LCD - 3.2". This LCD is very compact, intelligent, and cost effective ($85). This display module is ready to become a GUI and is capable of becoming an interface controller for any application. It is designed with a PICASO processor, which is driven by a virtual core engine core EVE. The good thing about this LCD is that it integrates very highly sophisticated software that makes it compatible to almost any application. Among the many things that this component offers are: audio amplifier and speaker, micro SD card connector, lithium polymer battery support, and multiple general purpose input/output pins (including 12C and serial communications). The module of this LCD can be switched to "SGC" easily by just changing the firmware. This is also a resistive touch screen. The features of this device are:

- Low cost display graphic user interface
- 240 x 320 resolution
- 5 pin interface to any host device
- Powered by PICASO processor
- 14 KB flash memory for code storage, 14kB of SRAM for user variables, and 14KB shared
- 2 asynchronous hardware serial port
- 1 x 12C interface
- 8 x 16 bits timer with 1 millisecond resolution
- 13 general purpose I/O pins
- micro SD card adapter
- DOS compatible file access
- Lithium Polymer battery
- audio pin driver for wav files
- audio amplifier
- built-in 4DGL graphics

- full color images
- supports all windows fonts
- 30 pin header I/O expansion for future plug-in daughter boards
- 4.0 - 5.5 V range operation
- display viewing area: 48.60 x 64.80 mm
- 4 corner plates with 2.7 mm holes for mechanical mounting

The LCD chose for this project was: serial TFT LCD 3.2". The main reason for choosing it is because the other option was more efficient for Arduino projects. For this device it was decided to utilize any Arduino board or Arduino parts. Both of the selections of touch screens are cost effective and the size is ideal for S.H.E.M.S. In addition, this specific LCD has much more features than the first option. The range voltage is ideal, it has better graphics, and more storage. The resolution is better and it gives option for SD card adapter. All images are full color and it supports all windows fonts (which is ideal because during the interface it is possible to customize the screen as desired). Below table 17 compare the different LCD's considered. Also, tables 18 through 24 show the different pinouts and characteristics for the LCD chosen.

Table 17: Comparison Between the two LCD's[ix]:

aR LCD - 3.5"	Serial TFT LCD - 3.2"
6 - 9 V operating voltage	Low cost display graphic user interface 4 corner plates with 2.7 mm holes for mechanical mounting
USB mini-B cable	240 x 320 resolution
Arduino Compatible	5 pin interface to any host device
3.5" Color LCD	Powered by PICASO processor
320 x 240 Resolution	14 KB flash memory for code storage, 14kB of SRAM for user variables, and 14KB shared
LCD Backlight	2 asynchronous hardware serial port
500:1 Contrast ratio	1x 12C interface
16 bit GPU	8 x 16 bits timer with 1 millisecond resolution
4MB Flash Memory	13 general purpose I/O pins, micro SD card adapter, DOS compatible file access, audio pin drivers for wav files, audio amplifier, support for all windows fonts, 30 pin header I/O expansion for future plug-in daughter boards, 4.0 – 5.5 V operation range, display viewing area: 48.60 x 64.80 mm

Table 18: H1 Pin Outs (I/O Expansion Header)[x]:

Pin	Symbol	I/O	Description
1	IO1	I/O	General Purpose Input Output 1 Pin
2	SPK-	O	Speaker Output It -ve, for external Speaker
3	IO2	I/O	General Purpose Input Output 2 Pin
4	SPK+	O	Speaker Output +ve, for external Speaker
5	IO3	I/O	General Purpose Input Output 3 Pin
6	SCL	O	I2C Clock Output
7	IO4	I/O	General Purpose Input Output 4 Pin
8	SDA	I/O	I2C Bidirectional Data
9	IO5	I/O	General Purpose Input Output 5 Pin
10	N/C	-	Not connected
11	GND	P	Supply Ground
12	N/C	-	Not connected
13	GND	P	Supply Ground
14	+5V	P	Supply Input +ve, 4.0V to 5.5V, 5.0V nominal
15	BUS7	I/O	IO Bus (Bus0...7) bit 7
16	AUDIO	I/O	Audio input or Output, TTL Line level
17	BUS6	I/O	IO Bus (Bus0...7) bit 6
18	AUDENB	I	Audio Amplified Enable, Active High (5V)
19	BUS5	I/O	IO Bus (Bus0...7) bit 5
20	RES	I	Master Reset, Active Low (GND) (Refer H2 Pinout)
21	BUS4	I/O	IO Bus (Bus0...7) bit 4
22	3.3V OUT	P	3.3V Output, 20mA Max supply
23	BUS3	I/O	IO Bus (Bus0...7) bit 3
24	RXO	I	Asynchronous serial port 0 receive pin. COM0 (same as the RX pin on the H2 Programming Header)
25	BUS2	I/O	IO Bus (Bus0...7) bit 2
26	TX0	O	Asynchronous serial port 0 transmit pin. COM0 (same as the TX pin on the H2 Programming Header)
27	BUS1	I/O	IO Bus (Bus0...7) bit 1
28	TX1	O	Asynchronous serial port 1 transmit pin. COM1
29	BUS0	I/O	IO Bus (Bus0...7) bit 0
30	RX1	I	Asynchronous serial port 1 receive pin. COM1

Table 19: P1 Pin Outs (Lithium Battery Header)[xi]:

Pin	Symbol	I/O	Description
1	+	P	Lithium Ion or Polymer 3.7V Battery +ve Terminal
2	+	P	Lithium Ion or Polymer 3.7V Battery +ve Terminal
3	N/C	-	Not connected
4	N/C	-	Not connected
5	-	P	Lithium Ion or Polymer 3.7V Battery -ve Terminal
6	-	P	Lithium Ion or Polymer 3.7V Battery -ve Terminal

Table 20: H2 Pin Outs (Programming Header)[xii]:

Pin	Symbol	I/O	Description
1	N/C	-	Not Connected
2	RES	|	Master Reset Signal. Internally pulled up to 3.3V via a 10K resistor. An active Low pulse greater than 2 micro-seconds will reset the module. If the module needs to be reset externally, only use open collector type circuits. This pin is not driven low by an internal condition. The host should control this pin via one of its port pins using an open collector/drain arrangement
3	N/C	-	Not Connected
4	GND	P	Supply Ground
5	N/C	-	Not Connected
6	RX	|	Asynchronous Serial Receive pin, TTL level. Connect this pin to the Transmit (Tx) signal of other serial devices. Used in conjunction with the Tx pin for programming this microLCD. This pin is tolerant up to 5.0V levels.
7	N/C	-	Not Connected
8	TX	O	Asynchronous Serial Receive pin, TTL level. Connect this pin to the Transmit (Rx) signal of other serial devices. Used in conjunction with the Rx pin for programming this microLCD. This pin is tolerant up to 5.0V levels.
9	N/C	-	Not Connected
10	+5V	P	Main Voltage Supply +ve input pin. Reverse polarity protected. Range is 4.0V to 5.5V, nominal 5.0V.

General Characteristics:

Table 21: Recommended Operating Conditions[xiii]:

Parameter	Conditions	Min	Type	Max	Units
Supply Voltage (VCC)		4.0	5.0	5.5	V
Operating Temperature		-10	-	+60	Celsius
Input Low Voltage (VIL)V	VCC = 3.3V, all pins	VGND	-	0.2VCC	V
Input High Voltage (VIH)	VCC = 3.3V non 5V tolerant pins	0.8VCC	-	VCC	V
Input High Voltage (VIH)	All GPIO pins, RX0 and TX0 pins	0.8VCC	-	5.5	V
Reset Pulse	Ext. Open Collector Reset	2.0	-	-	Us

Table 22: Global Characteristics Based on Operating Conditions[xiv]:

Parameter	Conditions	Min	Type	Max	Units
Supply Current (ICC)	VCC = 5.0V, heavily depends on screen usage conditions, sleep mode	-	155	-	mA
Output Low Voltage (VOL)	VCDC = 5.0V, IOL = 3.4mA	-	-	0.4	V
Output High Voltage (VOH)	VCC = 5.0V, IOL = -2.0mA	3.2	-	-	V
Capacitive Loading	All pins	-	-	50	pF
Flash Memory Endurance	PICASO PmmC Programming	-	10000	-	E/W

Table 23: Optical Characteristics[xv]:

Parameter		Condition	Min	Type	Max	Units
Contrast Ratio (Centre point)		Back-light On	300	350	-	-
Luminance of white (Centre Point)		Back-light On	200	220	26-	Cd/m^2
White Uniformity		Back-light On	80	-	-	%
Response Time	Rising + Falling	Back-light On	-	25	-	ms
Color Chromaticity	White, Wx	Back-light On	0.273	0.313	0.353	
	White, Wy		0.289	0.329	0.369	
	Red, Rx		0.574	0.624	0.674	
	Red, Ry		0.318	0.368	0.418	
	Green, Gx		0.300	0.350	0.400	
	Green, Gy		0.500	0.550	0.600	
	Blue, Bx		0.093	0.143	0.193	
	Blue, By		0.069	0.119	0.169	
Viewing Angle	Vertical above Centre	Contrast Ratio > 10	60	60	60	Degrees
	Vertical below Centre		60	60	60	
	Horizontal Left of Centre		70	70	70	
	Horizontal Right of Centre		70	70	70	

Table 24: Touch Screen Characteristics[xvi]:

Parameter	Conditions	Min	Type	Max	Units
Linearity		-	-	<1.5	%
Terminal Resistance X	X film side	300	400	800	Ohm
Terminal Resistance Y	Y film side	300	600	800	Ohm
Durability - Scratch Test	Stylus Pen or Finger Sliding	100	-	-	K
Durability - Tap Test	Stylus Pen or Finger Press	1	-	-	Million
Transparency	Non Glare	80	-	-	%

4.5 Bluetooth Device:

There are a lot of different Bluetooth modems and devices to choose from. Each of them has their own characteristics and features that make them change their prices. For this project, the Bluetooth must have: good range, low power consumption, good hopping scheme, and easy to interface among others.

The first one to consider and the option chosen is the BlueSMIRF Silver. This device has a reasonable cost ($40) and its specifications suits this project's design very well. The downside is that the range is smaller than other Bluetooth devices. The specifications for the BlueSMIRF Silver are below in table 25.

Another Bluetooth device considered is the Bluetooth Mate Gold. This device has a little bit more range than the one that we selected, but is pricier (around $65 each one). The specifications for the Bluetooth Mate Gold are below in table 26.

The main difference between these two is range and transit. The Silver uses RN-42 and Gold uses RN-41 modules. RN-41 is a class 1 device and it can communicate up to 100 meters, but transmits at a higher power which consumes battery life in a shorter period of time. The RN-42 is a class 2 device, but limits the range up to 10 meters.

Table 25: BlueSMIRF Silver

Feature	Value
Approved Class 2 Bluetooth Radio Modem	Yes
Small radio measure	0.15 x 0.6 x 1.9"
Robust link and transmission distance	18m
Hopping scheme	Yes
Encrypted connection	Yes
Frequency	2.4 ~ 2.524 GHz
Operating Voltage	3.3 - 6 V
Serial Communication	2400 - 115200 bps
Operating Temperature	-40 ~ +70C
Built-in antenna	Yes
Dimension	45 x 16.6 x 3.9 mm

Table 26: Bluetooth Mate Gold

Feature	Value
Arduino compatible	Yes
Class 1 Bluetooth Radio	Yes
Robust link distance	100 m
Lower power consumption	25 mA
Hopping scheme	Yes
Encrypted connection	Yes
Frequency	2.4 ~ 2.524 GHz
Operating Voltage	3.3 - 6 V
Temperature	-40 ~ +70 C
Serial Communication	2400 - 115200 bps
Built in antenna	Yes
Dimensions	1.5 x 0.65"

Also, another Bluetooth device taken into consideration was the Bluetooth Mate Silver. This is very similar to the BlueSMIRF Silver, but the main difference is that it is only designed to be used in Arduino Pros and LilyPad Arduinos. It is very efficient in serial pipe that is any stream from 2400 to 115200 bps pass seamlessly from the computer (main controller) to the desirable target. It is classified as RN-42, which makes it perfect for short range battery powered applications. It uses only 26 micro Amperes when in sleeping mode and even though it is in idle state, it can be discoverable and connectable. It can be used in a lowest power profile for certain applications. The voltage regulators are similar to the ones described above: 3.3 - 6 V DC and for the RX and TX pins: 3 - 6 V DC tolerant. The specifications for the Bluetooth Mate Silver are below in table 27.

Since it is not desirable to have Arduino Boards in the project, some other Bluetooth devices must be taken into consideration. The decision is based on the fact that most companies and possible investors of this project don't like the Arduino boards. And, all of the above Bluetooth devices mentioned used the Arduino board.

Table 27: Bluetooth Mate Silver

Feature	Value
Arduino Compatible	Yes
Class 2 Bluetooth Modem	Yes
Power Consumption	25mA
Hopping scheme	Yes
Encryption	Yes
Frequency	2.4 ~ 2.524 GHz
Operating Voltage	3.3V - 6V
Serial Communication	2400 - 115200 bps
Operating Temperature	-40 ~ +70 C
Built-in antenna	Yes
Dimension	1.75 x 0.65"

4.5.1 Non-Arduino Boards Bluetooth devices:

Bluetooth SMD Module - RN-41: It is a small, powerful and easy to use Bluetooth. Its price is a great advantage (about $25) and it is from Roving Network. This specific device is created to substitute serial cables and the stack is completely encapsulated. The users only see the characters being transmitted back and forth.
Features include:

Table 28: Bluetooth RN-41

Feature	Value
Fully Bluetooth Module	Yes
FCC Certified	Yes
Fully configurable UART	Yes
Data rates	3Mbps
Low power sleep mode	Yes
Operating voltage	3.3V
Status pins	Yes
Class 1 power output	Yes

Bluetooth SMD Module - RN-42-HID: This one is also from Roving Networks, but it comes with a firmware configured for HID protocol. HID stands for "Human Interface Device", which is the communication protocol, used between users and computer devices such as mouse, keyboard, and joystick among others. The good advantage is that this device is simple and powerful because it creates wireless peripheral devices that can be universally recognized without the need of installing new special drivers. This device is perfect for short range battery operated devices. It also has multiple user configurable power modes that allow the user to dial in the lowest power profile for a given application.
Other features include:

Table 29: Bluetooth RN-42

Feature	Value
FCC and SIG certified	Yes
Low power sleep mode	Yes
Power Operation	3.3 V
Status pin	Yes
Class 2 power output	Yes
Lower power consumption	26 uA

From these last two Bluetooth devices, the one that was chosen for the project was the Bluetooth SMD Module - RN-42-HID. The reason for that is that this offers more features that the other one doesn't. This particular Bluetooth device offers the HID protocol, which is very convenient in the creation of the project. In addition, the current offered by this device while in sleep mode is perfect because still with such low current the device can be discoverable and connectable. It is low power (which is ideal for the project), and also it offers different power modes. This is ideal for S.H.E.M.S. because the main goal of the project is to not only offer the desirable information to the consumers in terms of how much power they are consuming, but also for them to have a low power device itself for them to use home. Last but not least, the price is ideal: about $20 each one. Below, Table 30 shows the comparison between the two most important Bluetooth devices considered.

Table 30: Comparison Between the Bluetooth Considered[xvii]:

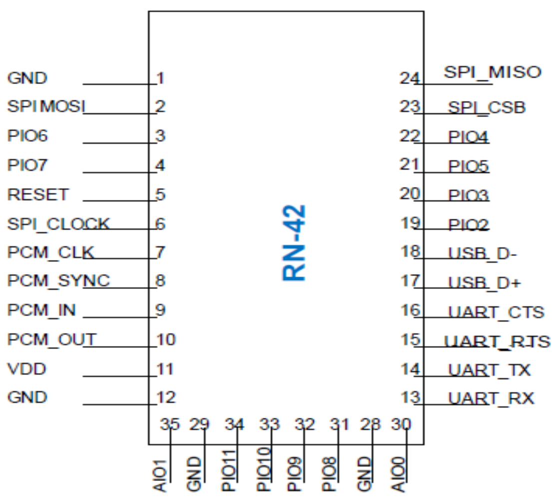
Bluetooth SMD Module - RN-41	Bluetooth SMD Module - RN-42-HID
Fully Bluetooth module	FCC and SIG certified
FCC certified	Low power sleep mode
Fully configurable UART	3.3V operation
Data rates of the UART: 3Mbps	Status pin
Low power sleep mode	Class 2 power output
3.3 V	Only 26uA in sleep mode, which makes it still being discoverable and connectable while sleeping
Status pin	Yes
Class 1 power output	Yes

4.5.2 Configuration:

Bluetooth Pin Configuration:

Pinout: This is the pinout for the Bluetooth device chosen. Figure 5 shows how to connect the device when used for the central hub and satellites.

Figure 5: Bluetooth Pin Configurations[xviii]:



Tables 31 through 36 below show how to correctly use the pinouts based on the different characteristics for the Bluetooth device chosen.

Table 31.1: Pinout[xix]:

Pin	Name	Description	Default	Voltage
1	GND			0V
2	SPI MOSI	Programming Only	Not Connected	3V
3	PIO6	Set BT master (High = auto-master mode)	Input to RN42 with weak pulldown	0V - 3.3V
4	PIO7	Set Baud rate (High = force 9600, Low = 115K or firmware setting)	Input to RN42 with weak pulldown	0V - 3.3V
5	RESET	Active Low reset	Input to RN42 with 1K pulldown	
6	SPI_CLK	Programming Only	Not connect	
7	PCM_CLK	PCM interface	Not Connect	
8	PCM_SYNC	PCM interface	Not Connect	
9	PCM_IN	PCM interface	Not Connect	
10	PCM_OUT	PCM interface	Not Connect	
11	VDD	3.3V regulated power input		
12	GND			
13	UART_RX	UART receive input	Input to RN42	0V - 3.3V
14	UART_TX	UART transmit output	High level output from RN42	0V - 3.3V
15	UART_RTS	UART RTS, goes High to disable host transmitter	Low level output from RN42	0V - 3.3V
16	UART_CTS	UART CTS, if set High, disables transmitter	Low level input to RN42	0V - 3.3V
17	USB D+	USB port	Pull up 1.5K when active	0V - 3.3V
18	USB_D-	USB port		0V - 3.3V
19	PIO 2	Status, High when connected, Low otherwise	Output for RN42	0V - 3.3V
20	PIO 3	Auto discovery = High	Input for RN42 with weak pull down	0V - 3.3V
21	PIO 5	Status, toggles based on state, Low on connect	Output for RN42	0V - 3.3V
22	PIO 4	Set factory defaults	Input to RN42 with weak pull-down	0V - 3.3V
23	SPI_CSB	Programming only	Not connected	
24	SPI MISO	Programming only	Not connected	
25	GND	GND for RN42-N		
26	RF PAD	RF for Pad for RN42-N		
27	GND	GND for RN42-N		
30	AIO 0	Optional analog input	Not used	
31	PIO 8	Status (RF data rx/tx)	Output from RN42	0V - 3.3V
32	PIO 9	IO	Input to RN42 with weak pull down	0V - 3.3V

Table 31.2: Pinout

33	PIO 10	IO (remote DTR signal)	Input to RN42 with weak pull down	0V - 3.3V
34	PIO 11	IO (remote RTS signal)	Input to RN42 with weak pull down	0V - 3.3V
35	AIO 1	Optional analog input	Not used	0V - 3.3V

Bluetooth works seamlessly in 3.3V and 5V systems. The voltage for VCC and GND can go between 3.3V and 6V and the voltages for the input signals go between 3.3V and 5V. Also, the output voltages go from Low (0) to High (could be 5V or 6V depending on the configuration). The current consumption depends on the behavior of the device at that specific time, if it is idle or sleeping the current is 0.026 mA. And, if it is high, then it uses 25mA.

Table 32: Electrical Characteristics[xx]:

Parameter	**Min**	**Type**	**Max.**	**Unit**
Supply Voltage (DC)	3.0	3.3	3.6	V
Average Power Consumption				
Radio ON* (Discovery or Inquiry window time)		40		mA
Connected Idle (No Sniff)		25		
Connected Idle (Sniff 100 milli seconds)		12		
Connected with data transfer	40	45	50	
Deep Sleep Idle mode		26		

Table 33: Digital I/O Characteristics[xxi]:

2.7 < VDD < 3.0 V	**Min**	**Type**	**Max**	**Unit**
Input Logic Level Low	-0.4	-	+0.8	V
Input Logic Level High	0.7 VDD	-	VDD +0.4	V
Output Logic Level Low	-	-	0.2	V
Output Logic Level High	VDD-0.2	-	-	V
All I/O's default to weak pull down	+0.2	+1.0	5.0	uA

Table 34: Environmental Conditions[xxii]:

Parameter	**Value**
Temperature Range (Operating)	-40 C ~ 85 C
Temperature Range (Storage)	-40 C ~ 85 C
Relative Humidity (Operating) and Storage	<90%

Table 35: Range Characteristics[xxiii]:

Range	**RN-42**
After One Wall	60 feet
After Two Walls	55 feet
After Three Walls	36 feet

Table 36: Radio Characteristics[xxiv]:

Parameter	Frequency (GHz)	Min	Type	Max	Bluetooth Specification	Unit
Sensitivity @ 0.1%BER	2.402	-	-80	-86	<-70	dBm
	2.441	-	-80	-86		
	2.480	-	-80	-86		
RF Transmit Power	2.402	0	2	4	<4	dBm
	2.441	0	2	4		
	2.480	0	2	4		
Initial Carrier Frequency Tolerance	2.402	-	5	75	75	kHz
	2.441	-	5	75		
	2.480	-	5	75		
20dB bandwidth for modulated carrier		-	900	1000	<1000	kHz
Drift (Five slots packet)		-	15	-	40	kHz
Drift Rate		-	13	-	20	kHz
Max Modulation	2.402	140	165	175	140	kHz
	2.441	140	165	175		
	2.480	140	165	175		
Min Modulation					115	kHz

Assembly:

Most of the assembly is already done, there is a few the programmer/designer need to do about it. The Bluetooth needs to be connected to a device that can receive and send signal; but because this is a TTL-Level serial signal a Software Serial to connect the modem transmitters and receivers to the pinout.

Firmware:

A serial interface is like a pipeline for the Bluetooth. The data goes into the module, passed through the Bluetooth connection, and the data out is passed out the serial side.

A microcontroller with UART needs to be connected to the header of the Bluetooth (of course, this microcontroller has to be able to send and receive serial data). Then, a configuration to the serial mode has is done at the same baud rate as the modem is configured for (in this case 1152000 bps). Then a connection with another Bluetooth device has to be done: pairing process.

Configurations Modes:

- Command Mode: configures the module. Here are the Bluetooth names, baud rate, PIN code, and data rate can be modified as needed.
- Data Mode: the data received in the Bluetooth is passed through it (TX pin) and then piped out of the connection through the RX pin

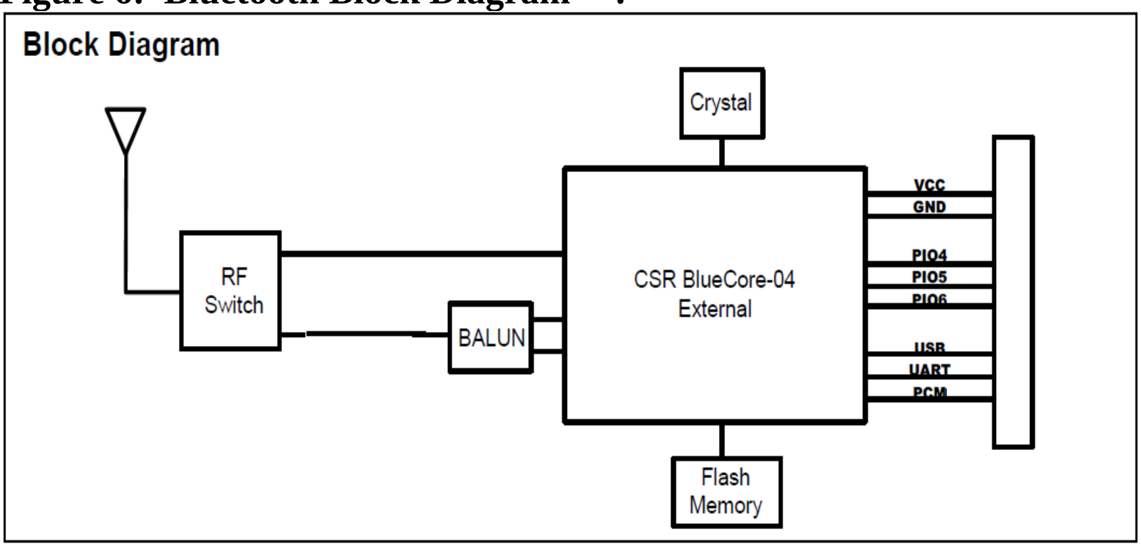
Timer:
The Bluetooth device has a configuration timer. It is activated as soon as the Bluetooth is turned on and the programmer/designer is unable to run configuration mode unless power cycle.

The LED lights of the Bluetooth indicate its behavior at a specific situation. Refer to the table 37 shown below.

Table 37: LED Lights[xxv]:

Mode	Stat Blink Rate	Notes
Configuration	10 per second	Module is *in* config mode.
Startup/Config Timer	2 per second	Module is not in config mode, but the configuration timer is still counting.
Discoverable/Inquiring/Idle	1 per second	Not in config mode, and the config timer has run out.

Figure 6: Bluetooth Block Diagram[xxvi]:



4.5.3 Why using Alpha RF transceiver:

The main reason for having alpha RF transceiver is that they are extremely cost effective but very high in performances, which is exactly what is needed for the device. The transceiver can transmit/receive up to 115Kbps at a maximum of 300m. Also, another reason of choosing it is the voltage at which operates. This is, 2-5V, and can sleep at a very low current, which is ideal for the device. In addition, the module can wake intermittently and can provide direct control outputs to a microcontroller, which makes it very suitable and ideal for a battery operated project. This module can suit one-to-one multi-node wireless links applications like for example: building security, POS and inventory tracking, remote process monitoring, etc. In the case of S.H.E.M.S, it is indeed a remote process monitoring system that suits perfectly the description of the alpha RF transceiver.

The module of the transceiver facilitates the compliance with FCC and ETS requirements. The receiver employs Zero-IF approach with I/O demodulation allowing it to use a minimal number of external components on a typical application.

The tables below 38 and 39 show the DC and AC characteristics for the transceiver.

Table 38: DC Characteristics[xxvii]:

Symbol	Parameter	Remark	Minimum	Typical	Maximum	Unit
$L_{dd\_TX\_0}$	Supply Current	4.33Mhz band 915MHz band		13 17		mA
$L_{dd\_TX\_PMAX}$	Supply Current	4.33Mhz band 915MHz band		21 25		mA
L_{dd_RX}	Supply Current	4.33Mhz band 915MHz band		10 13		mA
L_x	Standby Current	Crystal and base band		3 0	3 5	mA
L_{pd}	Sleep mode current	All blocks off		0.3		uA
L_{lb}	Low battery detection			0.5		uA
V_{lb}	Low battery step	0.1 V per step	2.2		5.3	V
V_{lba}	Low battery accuracy			75		mV
V_{il}	Low level input				$0.3*V_{dd}$	V
V_{ih}	High level input		$0.7*V_{dd}$			V
I_{il}	Leakage current	$V_{il} = 0V$	-1		1	uA
I_{ih}	Leakage current	$V_{ih} = V_{dd}$, $V_{dd} = 5.4V$	-1		1	uA
V_{ol}	Low level inpu	$I_{ol} = 2mA$			0.4	V
V_{oh}	High level input	$I_{oh} = 2mA$	V_{dd}-0.4			V

Table 39.1: AC Characteristics[xxviii]:

Symbol	Parameter	Remark	Minimum	Typical	Maximum	Unit
Fref	PLL frequency		8	10	12	MHz
Flo	Frequency	4.33Mhz band 915MHz band	430.24 900.72		439.75 929.27	MHz
FLo	Frequency	4.33Mhz band 915MHz band	344.19 720.57		351.8 743.41	MHz
FLo	Frequency	4.33Mhz band 915MHz band	3516.28 1080.8		527.71 1115.1	MHz
BW	Receiver bandwidth	1 2 3 4 5 6	60 120 180 240 300 360	67 134 200 270 350 400	75 150 225 300 375 450	KHz
Tlock	PLL lock time	After 10MHz step hopping		20		Us
BR	Data rate	With internal digital demodulator	0.6		115.2	Kbps
BR_a	Data rate	With external RC filter			256	Kbps
		BW = 134KHz, BR =1.2Kbps, 433MHz band		-106	-100	
		BW = 134KHz, BR =1.2Kbps, 433MHz band		-102	-95	
AFCrang	AFC working range	dfFSK FSK deviation in the received signal		0.8*dfFSK		
RSa	RSSI accuracy			+/-5	0.4	dB
RSr	RSSI range			46		dB
Carssi	ARSSI filter			1		nF

Table 39.2: AC Characteristics

RSstep	RSSI program. state			6		dB
RSresp	DRSSI response time	RSSI output high, CARSSI = 5nF		500		us

Table 40: Electrical Parameters of the Alpha RF transceiver[xxix]:

Symbol	Parameter	Minimum	Maximum	Unit
Vdd	Positive power supply	-0.5	6.0	V
Vin	All pin input level	-0.5	Vdd +0.5	V
Iin	Input current except power	-25	25	mA
ESD	Human body model		1000	V
Tst	Storage temperature	-55	125	
Tlt	Soldering temperature (10s)		260	

Mesh Network:

For the implementation of Bluetooth and other devices, the network is an essential part. First, let's define what mesh network is. Mesh network is a network topology that captures and disseminates its own data. It also helps other nodes to propagate the data in the network. This Local Area Network (LAN) offers two different connection arrangements: full mesh topology and partial mesh topology. In the full mesh topology, all the nodes are connected to each other. On the other hand, in the partial topology some nodes are connected to all other nodes, but some other nodes are connected to only the nodes they most share data with. The great advantage of the mesh network (specially the full mesh network) is that if one of the nodes, for whatever reason, stops working then the data has a lot of other paths to take (data is not compromised). In order for the data to be compromised, all nodes have to be down. The big drawback of this technology is that it is expensive because of all the cables required. But, for the mesh network, the connections can be wired (like described above) or wireless.

Wireless Mesh Network:

In this network the connection is made through different wireless access points install in each network locale. Each of these user's locale is a providing, which means that they forward data from one point to another. The infrastructure is decentralized and simplified because each node only needs to transmit to the next node. The big advantage of the wireless mesh network is that people can communicate with each other regardless of the distance between them. Advantages of the wireless mesh network are:

- decreased need for internet gateways
- redundant backup technology (insures data security)
- ability to configure routes dynamically
- lower power requirements, which suits perfectly to this project device
- increased reliability: different paths in case one nodes goes down

In the mesh wireless network only one of the nodes need to be physically connected to the internet. That node then connects to the others wirelessly. The rest of the nodes just need to be plug to a traditional AC plugs or any other source of power. Another advantage to this network is that as more nodes are connected, the farther the signal travels and the stronger and faster the Internet connection becomes for the user. But, how is that possible? Well, for example, if the computer a user is utilizing is out of the nodes, then the user is tapping four times the bandwidth. Also, if the distance between nodes is reduced, the signal becomes more strength.

Other networks considered:

Star Network:

In the star network all the nodes are connected with one central/common node. Every node is indirectly connected with every other node through the central node. Here, the connections can be wire or wireless like with the mesh network. This technology works well when workstations are at scattered points. And, it is easy to remove or add nodes as needed. If one of the nodes (not the common one) is damaged or does not work properly, then the only node affected is that one because there is no other connection to that node other than the common node. But, if the common node fails, then all of the nodes will be affected because all nodes are connected to it.

Bus Network Topology:

In this topology, each node is connected to a common cable called the 'bus'. This network is simple and reliable. If one node fails, then there is no problem because the rest of the nodes can communicate with the others. For a major failure, then the cable needs to be broken somewhere. Limitations for this topology include: the length of the bus is limited, and it won't work good if the workstations are at scattered points (do not lie in a common line).

Ring Network:

Here, the nodes are configured as a closed loop. Adjacent nodes are directly connected and other pairs are indirectly connected. The data passes through one or more intermediate nodes. The ring topology is good when the workstations are at scattered points or the requirements are modest. Costs can be lower in this topology. System reliability is a concern because if the cable is cut somewhere, in order for those nodes to connect, the data has to pass through the rest of the nodes before getting to its destination. But, if two breaks of the cable occur, then there might be workstations that will be cut off. Even though of all this, the ring network is the most used technology nowadays.

The mesh network can be implemented through the use of the Bluetooth network discovery protocols. During the design of the implementation, it can be configured to use a mesh network and is not hard to do. The main disadvantage is that in order to do this, more power is going to be required to keep the mesh network working. Another possibility is to use a hoc mesh network that only uses the network while transmitting data, which will reduce the power utilization.

There are also devices that can be used to work as mesh networks, but this will replace the Bluetooth device and this is not desirable for the project device. Below some of the devices considered along with its main important features that, even though right now are not considered for the project device, can be really helpful in the future:

Table 41: Xbee 2mW RP SMA - Series 2 (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 40mA
Max Data rate	250 kbps
Output	2mW
Range	400 ft
Antenna Connector	RPSMA
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
External Antenna	Required
Cost effective	Yes

Table 42: Xbee 2mW U.FL Connection - Series 2 (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 40mA
Max Data rate	250 kbps
Range	400 ft
Antenna Connector	U.FL
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
External Antenna	Required
Cost effective	Yes

Table 43: Xbee Pro 63mW Wire Antenna - Series 2B (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 295mA
Max Data rate	250 kbps
Output	63mW
Range	1 mile
Antenna Connector	Wire
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
Cost effective	Not as cost effective as previous one

Table 44: Xbee 2mW Wire Antenna - Series 2 (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 40mA
Max Data rate	250 kbps
Output	2mW
Range	400 ft
Antenna Connector	Built-in
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
Cost effective	Not as cost effective as previous one

Table 45: Xbee Pro 63mW PCB Antenna - Series 2B (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 295mA
Max Data rate	250 kbps
Output	63mW
Range	1 mile
Antenna Connector	Built-in
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
Cost effective	Not as cost effective as previous one

Table 46: Xbee Pro 50mW U.FL Connection - Series 2 (ZigBee Mesh)

Feature	Value
Operating Conditions	3.3 V @ 295mA
Max Data rate	250 kbps
Output	50mW
Range	1 mile
Antenna Connector	Built-in
Fully FCC certified	Yes
ADC input pins	6 10-bit
Digital IO pins	8
Bit encryption	128
Configuration	Local or over air
Command set	AT or API
Cost effective	Not as cost effective as previous one

Table 47.1: Comparison Between All Considered Mesh Network Devices[xxx]:

Xbee 2mW RP SMA - series2 (ZigBee Mesh	XBee 2mW U.FL Connection - series2 (ZigBee Mesh)	XBee Pro 63mW Wire Antenna - series2B (ZigBee Mesh)	XBee 2mW Wire Antenna - series2 (ZigBee Mesh)	XBee Pro 63mW PCB Antenna - series2B (ZigBee Mesh)	XBee Pro 50mW U.FL Connection - series2 (ZigBee Mesh)
3.3V @ 40mA	3.3V @ 40mA	3.3V @ 295mA	3.3V @ 40mA	3.3V @ 295mA	3.3V @ 295mA
250kbps Max data rate	250kbps Max data rate2mW output (+3dBm)	250kbps Max data rate	250kbps Max data rate	250kbps Max data rate	250kbps Max data rate
2mW output (+3dBm)	400ft (120m) range	63mW output (+17dBm)	2mW output (+3dBm)	63mW output (+17dBm)	50mW output (+17dBm)
400ft (120m) range	U.FL antenna connector	1 mile (1600m) range	400ft (120m) range	1 mile (1600m) range	1 mile (1600m) range
RPSMA antenna connector	Fully FCC certified	Wire Antenna	Built-in antenna	Built-in antenna	Fully FCC certified
Fully FCC certified	6 10-bit ADC input pins	Fully FCC certified	Fully FCC certified	Fully FCC certified	6 10-bit ADC input pins

Table 47.2: Comparison Between All Considered Mesh Network Devices:

Xbee 2mW RP SMA - series2 (ZigBee Mesh	**XBee 2mW U.FL Connection - series2 (ZigBee Mesh)**	**XBee Pro 63mW Wire Antenna - series2B (ZigBee Mesh)**	**XBee 2mW Wire Antenna - series2 (ZigBee Mesh)**	**XBee Pro 63mW PCB Antenna - series2B (ZigBee Mesh)**	**XBee Pro 50mW U.FL Connection - series2 (ZigBee Mesh)**
6 10-bit ADC input pins	8 digital IO pins	6 10-bit ADC input pins	6 10-bit ADC input pins	6 10-bit ADC input pins	8 digital IO pins
8 digital IO pins	128-bit encryption	8 digital IO pins	8 digital IO pins	8 digital IO pins	128-bit encryption
128-bit encryption	Local or over-air configuration	128-bit encryption	128-bit encryption	128-bit encryption	Local or over-air configuration
Local or over-air configuration	AT or API command set	Local or over-air configuration	Local or over-air configuration	Local or over-air configuration	AT or API command set
AT or API command set	External Antenna Required	AT or API command set	AT or API command set	AT or API command set	External Antenna Required
External Antenna Required	Cost effective	Not as cost effective as the previous two, but still good price	Cost effective	Not as cost effective as some of the previous ones, but still cost effective	Not as cost effective as some of the previous ones, but still cost effective
Cost effective					

5.0 Wireless Technologies

S.H.E.M.S. main controller or central hub is connected wirelessly to the subsystems or satellites that will read and monitor the power of the appliance connected to it. It is important to assess the different methods that exist today to connect these instruments wirelessly. Different approaches to consider are:

5.1.1 Bluetooth Wireless Technology Devices:

Bluetooth devices are nowadays found almost everywhere in a lot of different devices, from smart phones to computers and home products. The Bluetooth is a short range communication technology. This technology is simple but it is also secure. The Bluetooth technology uses the 'pairing' to enable the connection between devices. Bluetooth allows any device with this technology to connect with each other as long as they are close to each other. Any device in a piconet can connect to up 7 other devices. The maximum range for a Bluetooth technology is 10 meters or 30 feet, but there is no limit so the manufacturers can implement or set their own range for the specific device. Bluetooth devices have a lot of benefits including: robustness, low power, and low cost. Bluetooth operates in an ISM (Industrial, Scientific, and Medical) band at 2.4 to 2.485 GHz. Also, Bluetooth use the adaptive frequency hopping, which is nothing more than detecting other devices nearby and avoiding their frequencies so their own signal won't be interfere. And because this technology uses low power consumption, the radios are powered down when inactive, which is a plus for this project because the main objective is to lower power.

5.1.2 Internet Wireless Technology:

Internet is another approach that can be used because the internet is the universal method today to be connected and in touch with people, devices, computers, etc. But, when using this approach the way that users access the information might have to be changed a little bit. An advantage of this is the availability of the users to enter to their information anytime, anywhere they want. But the disadvantage is that is too complex to design and implement.

And because the project is looking to create an app for Android, then there is no need to use the internet approach. The Bluetooth devices offer the services needed to implement and fulfill all the requirements of the project, at a cheaper price, less complexity, low power, and with the advantage of having this information with them at all times with the convenient app for Android.

The wireless device must have:

- Must have a good Range
- Must have a good Signal
- Protection of User's Information
- Smartphone Application interaction

6.0 Project Microcontroller Software Design Details

For the microcontrollers there are two sets of code written. One code is on the microcontrollers in the satellite monitoring stations and controls the devices in each satellite monitoring station. The other code is on the microcontroller in the central hub. Each code set has Bluetooth interactions. Only the central hub has an LCD touch screen display interactions, display options, database management, Bluetooth master options and Android Bluetooth application interface. Similarly only the satellite monitoring stations have the Hall Effect current sensor, relays and limited database capability.

6.1 Initial Design Architectures and Related Diagrams

We have our central hub operating with a main function that is able to call a Bluetooth function with send, receive and network functions, a database function with a cleanup function, a draw function, and a time and date function. When we want to get new data we have the main function call the Bluetooth function which in turn calls the send function and it sends a request for new data to each of the satellite monitoring stations, and then calls the receive class and have it wait in a standby listening mode for replies from the satellite monitoring stations. If a satellite monitoring station doesn't respond after five seconds time interval we resend the request for new data to that satellite monitoring station as many as three more times. After three times we assume that the satellite monitoring station has gone offline and sends a message alerting the user to this fact. We then move to the next satellite monitoring station and send a request to it. It will repeat this till all of the know satellite monitoring stations have been contacted and gotten a reply for data back. At this point the central hub sends out a request to all satellite monitoring stations in attempt to find any new satellite monitoring stations if there are less than five satellite monitoring stations. When the data is received from a satellite monitoring station it will be forwarded to the database function where it will all be stored according to which satellite monitoring station or device identification that it was received from. After all of the new data has been received and stored the database function will then call the cleanup function to sort and organize the newly received data. The cleanup function will determine what if any data should be combined, deleted or left alone. Once that is done the main function will call the draw function to display the data from the database function to the user. From there the user will be able to see the new and old data as a table, graph or both a table and a graph. The user will also be able to decide how far back they wish to see data from a given device or even all of the devices.

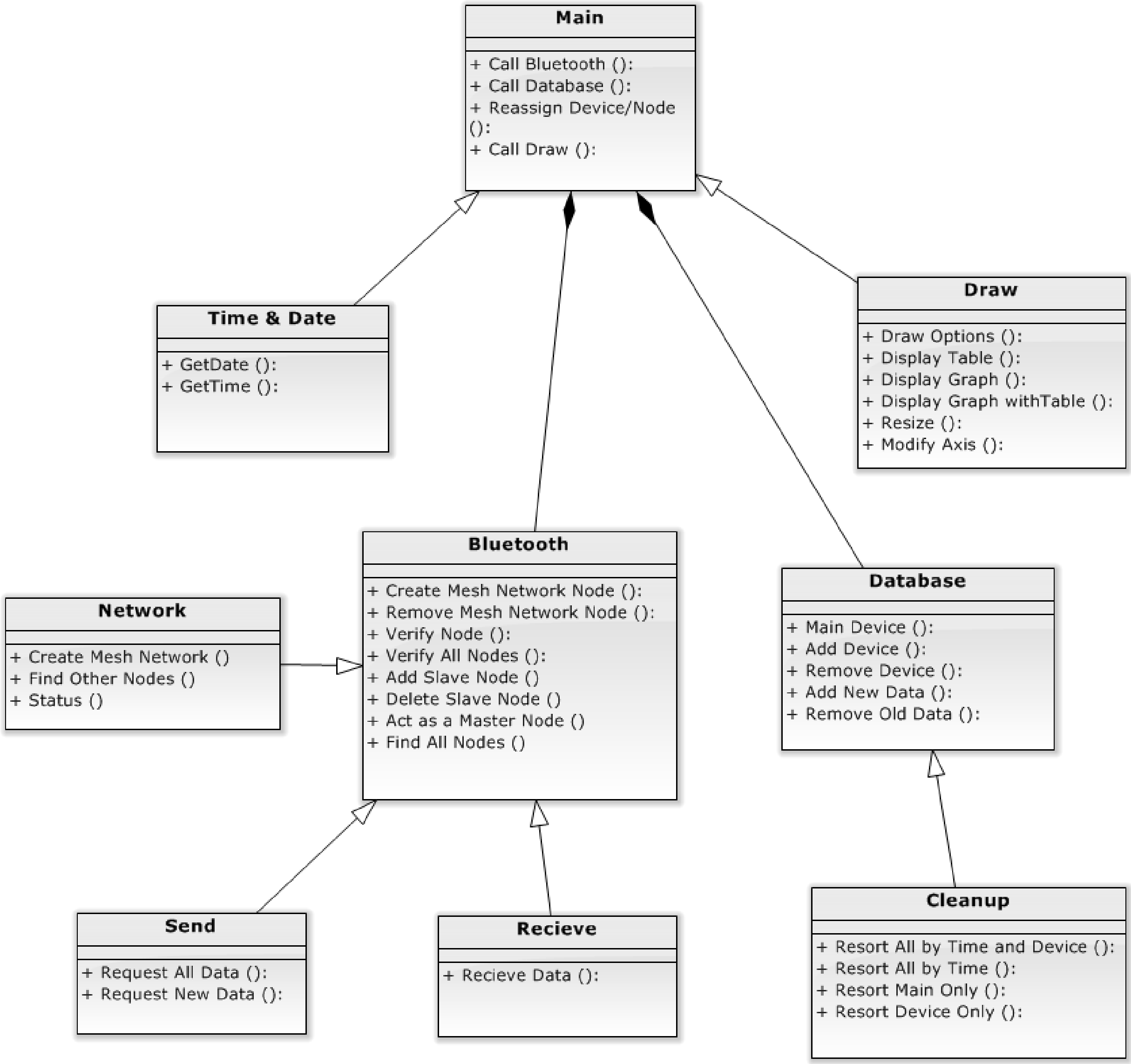


Figure 7: Central Hub Function Diagram

For our satellite monitoring stations we plan to have them only with a main function that is able to call a Bluetooth function with a send, receive and network functions, a date and time function and a limited database function with a current, voltage and relay functions. The Bluetooth's receive function will be up and running at all times when it is not actively sending data to the central hub. These satellite monitoring stations will be to eyes and ears of our project that gather all of the input we need. As a result we will plan to have five satellite monitoring stations with the ability to add or remove stations as needed in the future. This way we should be able to scale down to a single satellite monitoring station or up to thousands of satellite monitoring stations with little to no code changes.

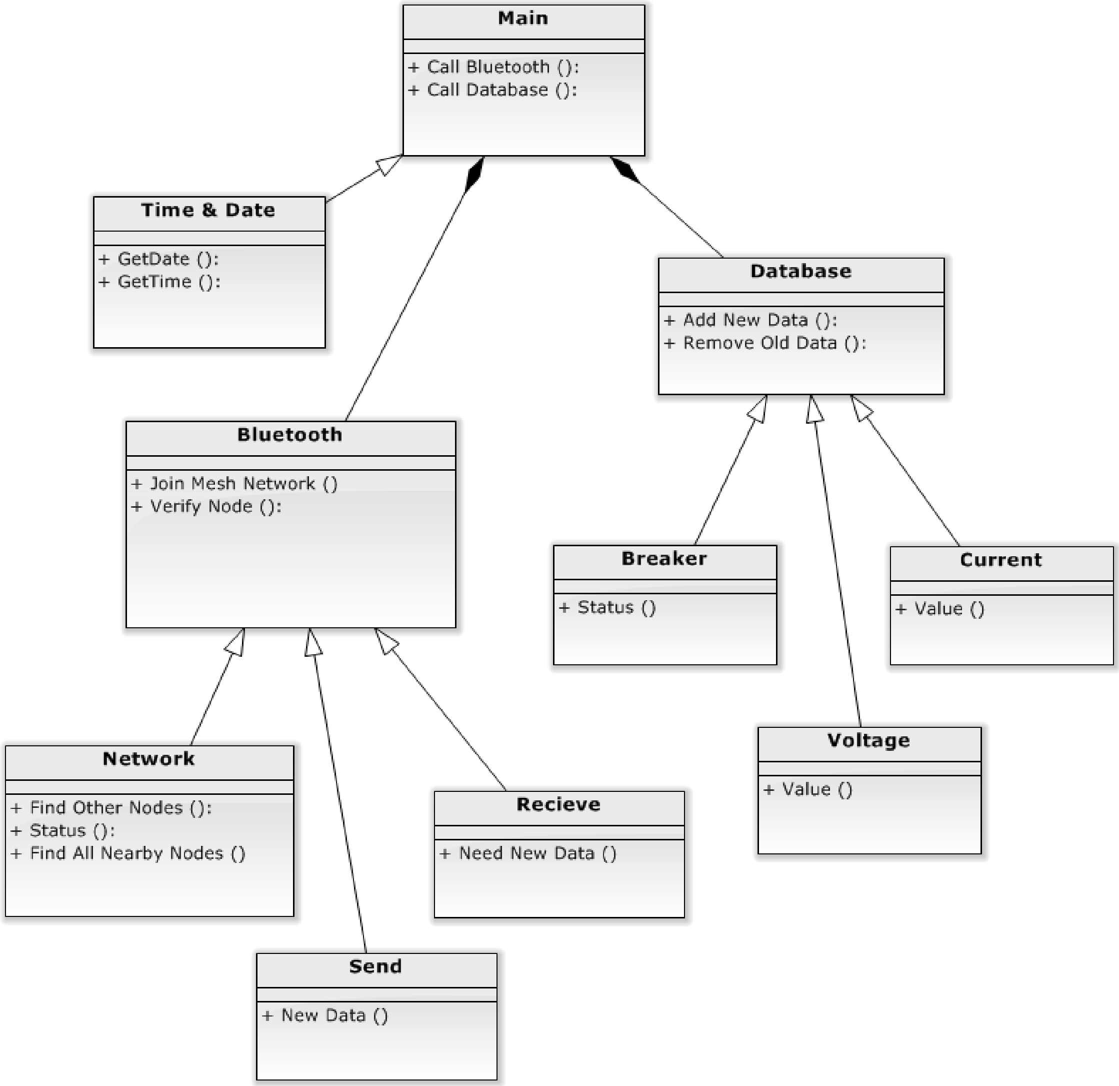


Figure 8: Satellite monitoring station Function Diagram

6.2 Database Design

We will use a database design in our central hub that is compatible with the SQLite database that we will be using in our Android application. The databases in our satellite monitoring stations will be akin to a simple list only for that single station. For our satellite monitoring stations we plan to sample the data once every second. This will allow us to construct an accurate view of the power being used and the money being spent every second of the every day. Each satellite monitoring station will only store the data for itself and not any of the other satellite monitoring stations. This will reduce the amount of space needed for data storage on each satellite monitoring station. Secondly after the central hub requests new data from a satellite monitoring station it will send all of its data. Once it has been confirmed that all of the sent data was received it will be deleted from that satellite monitoring station to help ensure that there is always plenty of space for more data on each satellite monitoring station.

The central hub on the other hand will store all of the data from all of the satellite monitoring stations. As a result the central hub will also have a larger storage drive in which to store all of this data. This data will rapidly grow in size and would soon become too large to handle in a timely manner. As a result we will be refactoring the data on a regular basis. After a day we plan to take the average, minimum and maximum of the data for each minute and then delete the data for each second of that minute. After a week we will go back and take the average, minimum and maximum of the data for each hour and again delete the data for each minute of that hour. After one month we will go back and take the average, minimum and maximum of that data day and again delete the data for each hour of that day. Ultimately we will only keep our daily data as an average, minimum and maximum for each day and delete all of the other data points for that day. At the end of each month we will input the average, minimum and maximum for that month into our database of data. This will allow the user to view their past months average, minimum and maximum as well as their daily average, minimum and maximum for each day as well as view their monthly and daily averages for the past years in which data has been collected. This will allow them to better detect, follow and change their energy usage habits so that they can use less energy and in turn save more money every day, week and month of the year.

As a result of this refactoring we are not concerned about the database getting to large and running out of room for more new data. Nor are we worried about the program running slowly or crashing as a result of the size of the database. This will allow us to use smaller storage devices to store the database which will in turn cut down on the cost of the end product.

6.3 Bluetooth Interactions and Encryption

Bluetooth uses a pre-shared link key between devices for authentication which we plan to use. This will be done using the Bluetooth 2.1 and higher device encryption for that shared link key. We however don't plan to use more than is needed for the shared key due to what we believe to be the low security risk operations of our device. We can in the future always increase the encryption to 256 bits or higher if needed should we decide we need a higher level of security.

The Bluetooth devices will need to have their network finding protocols modified as well to allow for the creation of an ad hoc mesh network between the satellite monitoring stations and the central hub when passing data back and forth. We however can also use the standard master-slave network protocols that Bluetooth was designed to use to reduce our power consumption if we need to. The only downside to using the master-slave network protocols is that they are not robust like the mesh network protocols are.

6.4 Touch and Swipe Interactions

The central hub will be the only device other than the Android application that will have an interactive touch screen display. We plan to use an LCD touch screen display for this on our central hub. We plan to allow the user to do basic single touch, multi touch and gesture detections. This will allow the use to resize the data being displayed, modify the display options, and select what data to display.

6.5 Data Display Options

The user will have the option of viewing the data as a graph, a table or a table with a graph. They will also be able to decide which satellite monitoring station or stations they wish to see data from or even if they wish to see the data for the entire building. They will be able to resize the graphs and tables to effectively zoom in or out as they so desire. They will also be able to give each satellite monitoring station a personal name such as hot water heater, living room TV, bedroom TV, fridge, Blu-ray player and so forth. They will be able to see the data from each second of the current day. They will also be able to see the data from as far back as seven days for every minute in terms of average, minimum and maximum values for that minute. They will also be able to see the data for each day as far back as one month for every hour in terms of average, minimum and maximum values for that hour. After the data is one month old they will only be able to see the data in terms of daily average, minimum and maximum values. This should be more than sufficient to allow them to identify trends in their energy usage for a given item as well as their energy usage for the entire building. They can then then learn to modify their energy usage habits and in turn save themselves some money. They can see which items are the worst offenders for drawing unwanted phantom energy when not in use as well as which items only draw a very small amount of phantom energy. From here they can decide which items they will completely turn off when not in use though the built in relays in each satellite monitoring station. They will also be able to decide what items they will turn off when they are not home like their hot water heater. As if they are not home they are likely not using the hot water, yet the hot water heater is always working to keep the their water nice and hot. They can decide to create a rule for it that will allow them to turn if off in the morning after they shower, and only turn it on again shortly before they arrive home that night so that they have hot water when they are home again. They could also decide to turn it off during the night while they are sleeping and only turn it on shortly before they plan to get up and shower in the mornings. They will also be able to see the amount of energy saved and in turn dollars saved by lowering their thermostat's air conditioning system by one degree in the summer or by raising the heater one degree in the winter. From there they can decide if they want to install a programmable thermostat in their house. Also they can actually see how much they do save by making that change as it can be hard to see what difference that change makes to your power bill when you have so many different devices plugged in and running or drawing phantom energy at once. This way they can actually see the worst offenders and stop them from costing them wasted money each month.

7.0 Project Application Software Design Details

We need to decide on an application operation system and then determine what versions of that operating system that we will support in our application. We will also need to decide how we will layout the code in terms of libraries to include, classes, functions, database type and format, formulas needed, Bluetooth interface, touch and swipe interface, display options, and anything else we decide to use in our application. We will also need to decide how the different parts of the application will all interact with each other.

7.1 Platform and OS Type and Version Selection

The two platforms we decided to look at are Apple and Android for our application. We have in our group both Iphones and Android phones. We decided to research each platform and then decide from there which platform or even both platforms to use.

First we researched the Apple iOS and soon found out that in order to publish an application to the app store you need to enroll in the Apple Development Program which cost $99[xxxi] a year. This for us was a major deciding factor to not go with an iOS. Another part of the equation was the fact that none of us had any experience with programing in the iOS or Apple OS, but this was also a plus for us as it would allow us to learn a new language and skill that could be valuable in the future to have.

Then we researched the Android platform. We liked the fact that it was free to use and develop applications to distribute. Also another plus for us was the fact that Android uses a java based programing language. Most of us have taken or had some java programing experience so that was a major plus for us. We did not however have any experiences with writing Android applications so we knew there would be a little bit of a learning curve. This however would be a good thing as it would further expand our programing backgrounds and knowledge. We made table 48 to simply showing our main pros and cons that we based our final decision off of below.

Table 48: Apple vs. Android for the Application

Concerns	Apple	Android
Cost	Con: $99 per year	Pro: Free
Past Experience	Con & Pro: None	Pro: Some Java
Hardware Required	Con: Apple Computer	Pro: Any Computer With Java
Concussion	We Will Not Use Apple	We Will Use Android

Now that we had decided to use the Android platform for our application we had to decide what Android versions we wanted to support and how far back we wanted to extend that support for. We had to decide between the following Android versions: KitKat, Jelly Bean, Ice Cream Sandwich, Honeycomb, Gingerbread and Froyo. Given that Jelly Bean was the most used platform we decided to go with that as our main platform and add support for others as we could. We decided to exclude versions before

Froyo as they don't support the current Google Play Store application. We also decided to use the current version of Jelly Bean which is 4.3 and then add support for the earlier 4.1.x and 4.2.x versions of Jelly Bean as well as we could while coding the application. The reason we decided to support the earlier versions of Jelly Bean is that as they are more widely used as of August 2013. We used the information from the Android website to find much of this information as well as for the information in table 49 and the pie chart of figure 9 below[xxxii].

Table 49: Android OS Distributions

Version	Codename	API	Distribution
2.2	Froyo	8	1.7%
2.3.3 – 2.3.7	Gingerbread	10	26.3%
3.2	Honeycomb	13	0.1%
4.0.3 – 4.0.4	Ice Cream Sandwich	15	19.8%
4.1.x	Jelly Bean	16	37.3%
4.2.x		17	12.5%
4.3.x		18	2.3%

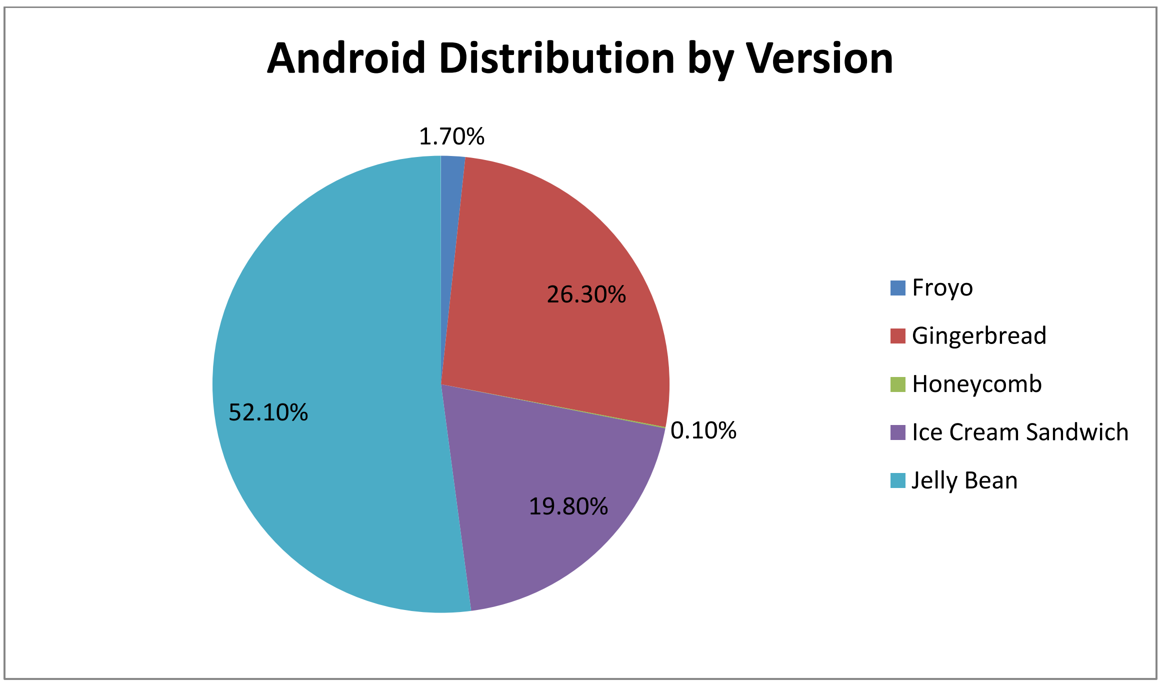


Figure 9: Android OS Distributions

7.2 Initial Design Architectures and Related Diagrams

We plan to have our application operate with a main class that is able to call the Bluetooth class, a database class, a time and date class and a draw class and have those classes then do their functions as needed. If we want to get new data we will have the main class call the Bluetooth class which will in turn call the send class and have it send a request for data to the central hub after which it will enter into receive mode for a specified time while it awaits the new data. If the data is not received it will resend the request and resume waiting for the data to be sent. If this happens 3 times in a row we will have it display and errors informing the user that it was unable to receive any data from the central hub and have the user check that they are within range of the central hub. If the data is received it will then forward that data to the database class. There that data will be sorted by device identification and placed into the appropriate fields. Once that is done the database cleanup class will be called. The cleanup class will then go over the new and old data to determine if any of that data should be combined, deleted, or left alone. Once that is done main will then call the draw class to display the data from the database. From there the user can then decide what data they want to see and how they wish to see it. They will be able to see that new data as a table or a graph. They will also be able to decide which devices they want to see that data for and how far back they wish to see it.

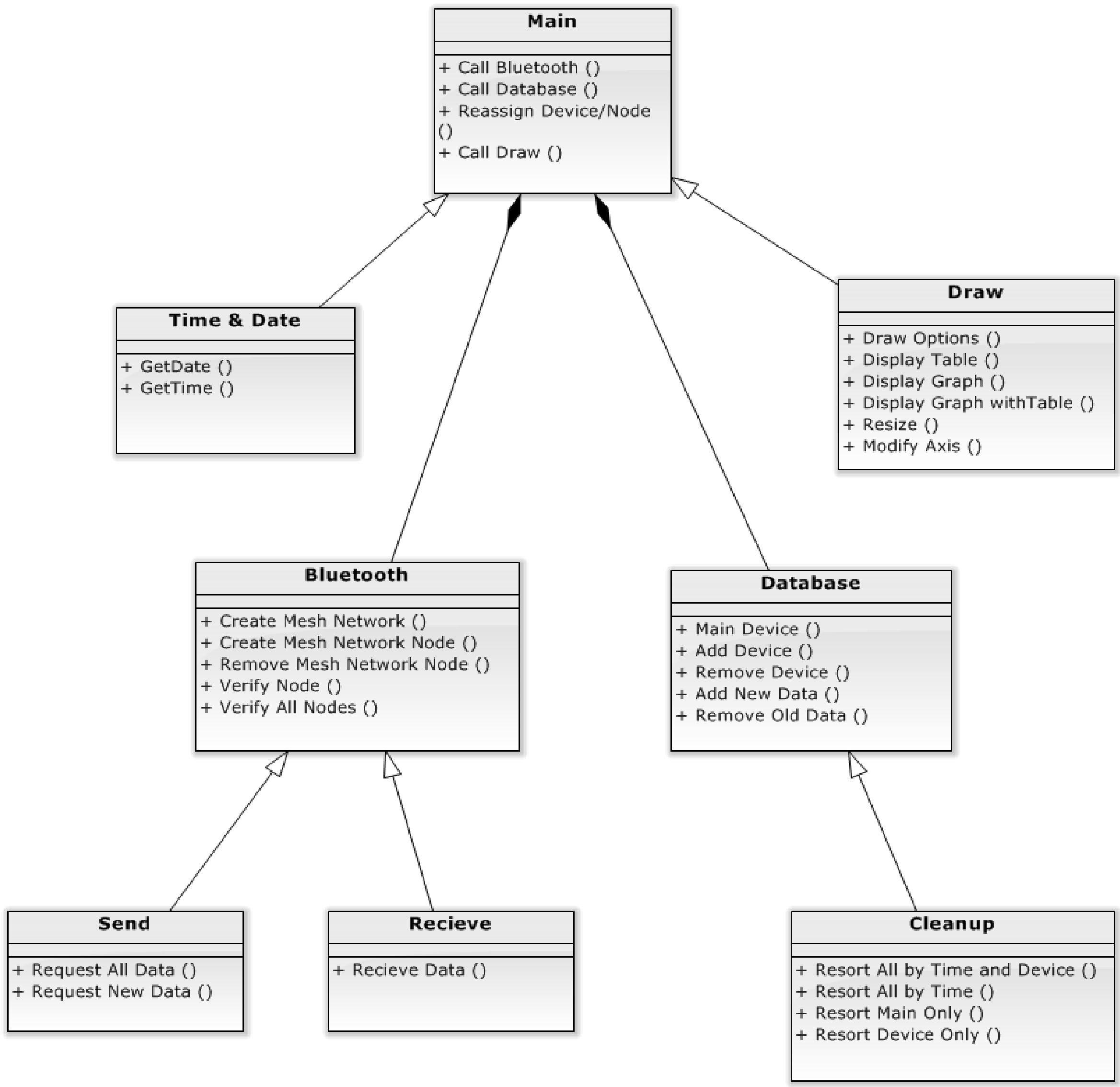


Figure 10: Android Application Class Diagram

This is an example of a request for new data from the central hub. This example doesn't show the calls that the central hub would be sending to the satellite monitoring stations.

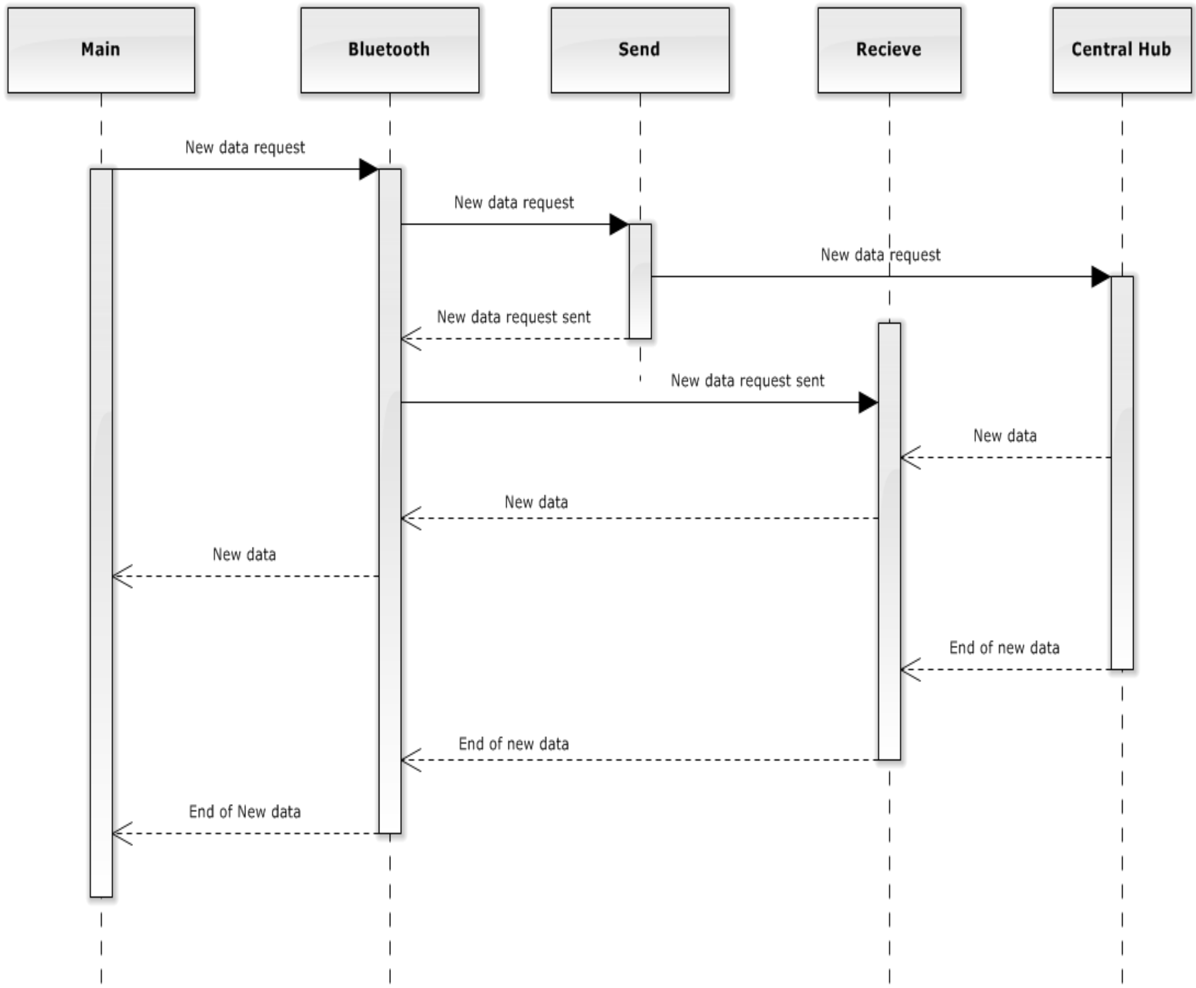


Figure 11: Application Requests New Data Sequence Diagram

We will allow requests for new data to be sent from the central hub as well as from the application. The only real difference is that when the application requests the data from the central hub that it is sent to the application as well. If the central hub sends a request for new data, that new data is not forwarded to the application right away. Unless the application is currently running and ready to receive that information.

This is an example of the application requesting new data from the central hub with only three satellite monitoring stations.

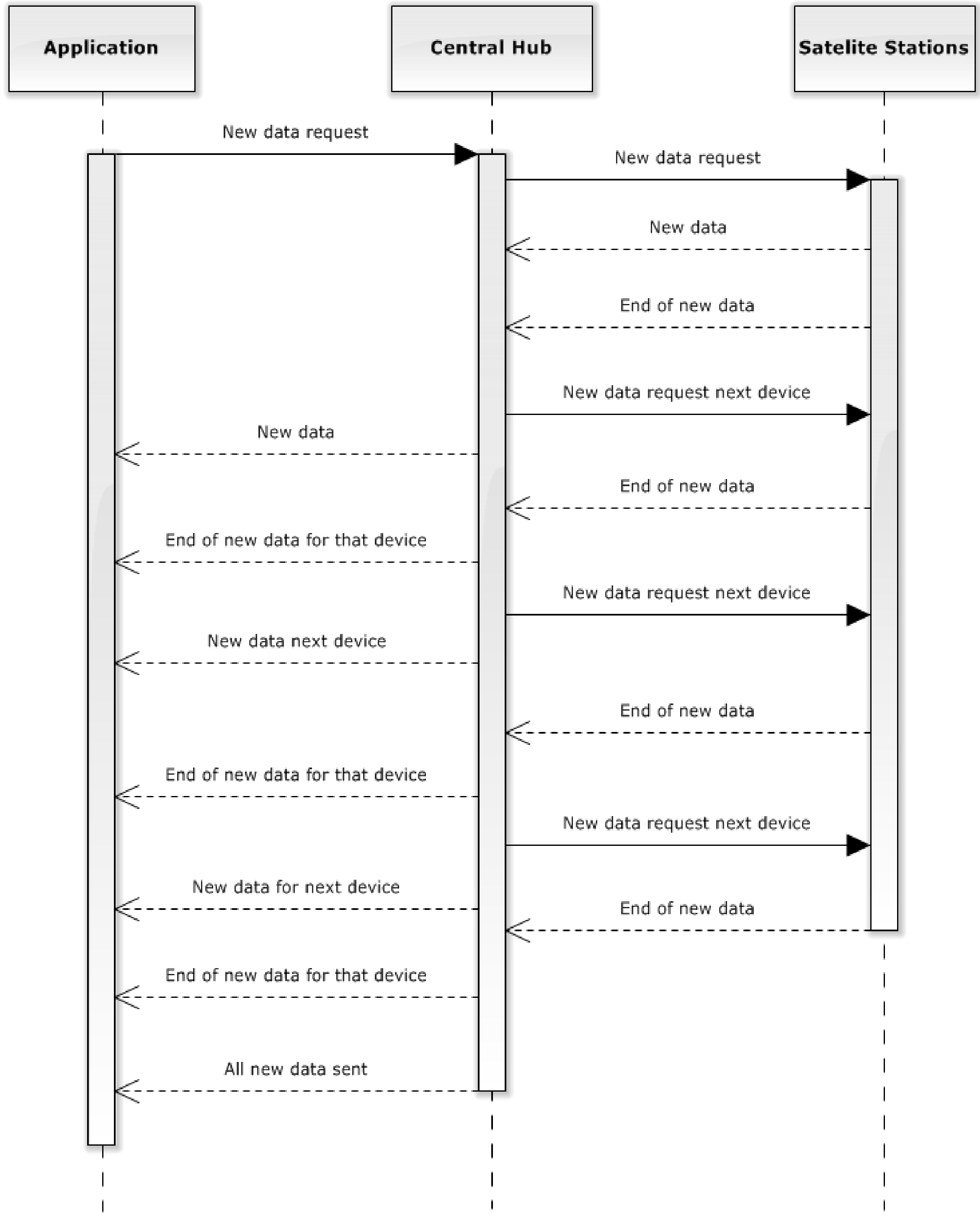


Figure 12: Application Requests New Data Sequence Diagram

This is the second case in which the application is not requesting any new data, but the central hub is requesting new data. This example shows that there are only three satellite monitoring stations currently, but that number can be increased without any problems.

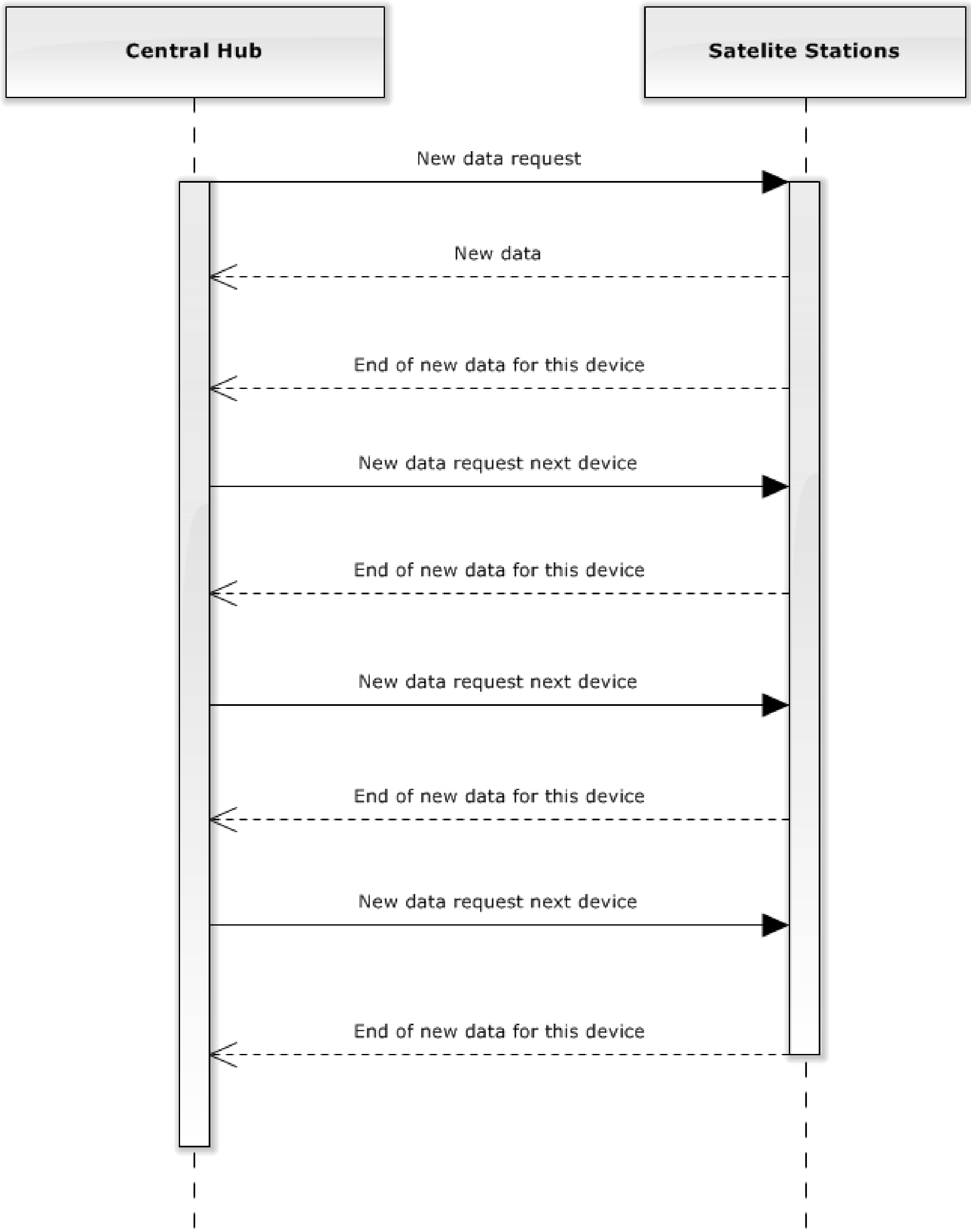


Figure 13: Central Hub Requests New Data Sequence Diagram

7.3 Database Design

We will use a SQLite database as that is compatible with the Android Jellybean versions we have decided to use to store our data. We plan to sample the data from out sensors every second of the day. After a day we plan to take the average, minimum and maximum of the data for each minute and then delete the data for each second of that minute. After a week we will go back and take the average, minimum and maximum of the data for each hour and again delete the data for each minute of that hour. After one month we will go back and take the average, minimum and maximum the data for each day and again delete the data for each hour of that day. Ultimately we will only keep our daily data as an average, minimum and maximum for each day, and delete all of the other data points for that day. At the end of each month we will input the average, minimum and maximum for that month into our database of data. This will allow the user to view their past months average, minimum and maximum as well as their daily average, minimum and maximum for each day as well as view their monthly and daily average for the past years in which the data has been collected. This will allow them the better detect, follow and change their energy usage habits so that they can use less energy and in turn save more money every day, week, month and year.

We are not concerned about the database getting to large and running out of room for storage nor are we concerned about it getting to large and causing the application to run slower due to all of the data that needs to be accessed. The reason for this is because we will be refactoring the data as we go to ensure that our database doesn't get overly bloated and cause problems. This decision was made early on to help us work with the limited amount of storage we have available to us and the large number of data points we are collecting. If we didn't do this the number of data points would very quickly grow to a point that they would take up more space than is available to us.

For example after 36 hours with just one station you would have 129,600 data points if you didn't refactor the data, but since we are refactoring the data you only have 44,640 data points which is about one third the number of data points. The amount of space saved grows even more the longer the system up and is running as the older the data the few data points we are keeping for it.

7.4 Bluetooth Interactions and Encryption

For the Bluetooth interactions we will be using the build in Bluetooth functionality and support that Jellybean already has. This will allow us to focus more on adding more functionality and content to the Android application. We will be using the standard built in secure Bluetooth 2.1 and higher device encryption for the link key that will keep our transmissions all secure enough. We at this time are not worried about someone listing to the channel and then intercepting and altering the data. Also we are not concerned at this time about someone hacking into our network and altering the data or turning devices on or off as they see fit. The reason for this is that we are more interested in the interactions between the devices themselves. If we have adequate time we will go back and improve upon the security protocols being used however, but not at this time.

We will be using the built in Bluetooth functionality to both send and receive data with the central hub. We don't at this time however plan to have the Android application interact with the satellite monitoring stations. Instead it will only interact with the central hub. This will allow us to simplify our Bluetooth interactions till we have them all working correctly and to our satisfaction. At that time if there is adequate time we can then work on allowing the Android application to interface directly with the satellite monitoring stations. Doing this however will also require us to modify the way the satellite monitoring stations interact with the central hub as well as how the central hub interacts with the Android application.

7.5 Touch and Swipe Interactions

For our Android application we will be using the basic single touch, multi touch, and gesture detection. We intend to allow the user to resize graphs and tables with gesture detections. They will also be using the touch to request the data be updated. They will also be able to decide how they wish to see the data. They will also be able to tap on the respective icon or swipe the screen to move to other display options, data options, settings and anything else we incorporate into the Android application.

7.6 Data Display Options

The user will have the option of viewing the data as a graph, a table or a graph with a table. They will be able to decide which satellite monitoring station or stations they see data from or if they just wish to see the overall usage for the entire building. They will be able to resize the graphs and tables to effectively zoom in or out. They will also be able to rename each satellite monitoring station as they see fit to best describe what it is monitoring. These personalized labels will allow them to better sort and see the data they are interested in. They will also be able to determine what time scale they want to see the data in. They will be able to see data from each second of the current day. They will also be able to see the data from as far back as seven days for every minute in terms of average, minimum and maximum values over that minute. They will also be able to see the data for each day for as far back as one month for every hour in terms of average, minimum and maximum values over that hour. After data is one month old they will only be able to see the data in terms of daily average, minimum and maximum values. This should be more than sufficient to allow them to detect and monitor trends in their spending habits as well as decide what items they may want to turn completely off when they are not around so as to stop them from drawing phantom energy. This will also be useful to see how your energy usage fluctuates though out the year for the different seasons. This can in turn allow the user a way to anticipate what months they will spend the more and which months they will spend less and to budget accordingly for those months. This way if a user sees they spend an average of $200 a month over the course of the year, but they spend almost $300 dollars a month in the hot summer months and only $100 a month in the cooler fall and winter months they can budget accordingly. This can help them from having an unexpected surprise when the bill comes as well. Also they can use this information to decide to raise their thermostat stetting to a higher temperature in the summer and see how that impacts their monthly bill. They may find that they can raise their thermostat in the summer by one or two degrees and cut your energy bill significantly when your home and three to five degrees when you're not home. This way you can get a programmable thermostat and set it to when you leave in the morning to set the temperature for the air conditioner to come on only when it gets hotter and then closer to when you return home again lower the thermostat temperature to a more comfortable setting.

8.0 Design summary of Hardware

The project consists of different components house in two main hardware parts: The house hub (1) and satellite monitoring node (4). Each house hub contains a power supply, microcontroller, relay and a LCD monitor. In each satellite monitoring node there are a power supply, microcontroller, relay, plug and a wireless communication component, or in our case the Bluetooth main.

Relevant to the design are the dimensions of each of the components to be able to fit them in a single enclosure for each individual enclosed part. The accuracy, efficiency and functionality of each component in the hardware design was important but most important of all for this specific smart meter rather than extra features we focus on the main theme of saving energy specially standby power.

The power supply is another important element of the main hardware parts both the house hub and the satellite monitoring node, also a type of emergency response power element like a 9V battery is included in both the node and the hub.

Gratefully the use of a wireless element like the Bluetooth mate and Bluetooth snirf eliminates the need for extra wiring and cables that otherwise we would have add lots of bulks to the PCBs.

The housing enclosure for each main part: the house hub and the satellite monitoring node will have dimensions based on two main considerations: how high will the screws holding the board in place, will make the PCB stand inside the case; and how wide is the minimum the board could be to hold as many components as possible, and the maximum size of PCB able to be a reasonable size of device that could be plug into the wall. This two criteria should be taken into consideration for both the satellite monitoring node and the house hub. The discussion on PCB vendor requirements will be address in the next section Project Prototype and Coding as well as specific dimensions.

8.1 Microcontroller

On the market there are many microcontrollers with a different CPU sizes that varies from ultralow power consumption to high current consumption. They are many different technical features to consider. The project functionality and specifications of hardware components and software architecture should be consider first to determine the right microcontroller. Also, there are many vendors and different architectures among the most popular: ARM, Atmel AVR, Cypress Semiconductors, Intel, Infineon, Silicon Laboratories, STMicroelectronics, Texas Instruments, PowerPC, Freescale (before Motorola) and many others. Most of the aspects to consider when selecting a microcontroller are based in the following:
Ultralow or high power consumption
Real time and interrupt latency
Digital control using PWM (pulse width modulation) or using TRIACs
Serial ports like UARTs

Type of serial communication interface like I2C, SPI or CAN
Presences of in chip debug circuitry
Programming environment or type of high level language usage
Mixed signal (Analog/Digital) or single signal (Digital)
I/O Usage
Power supply: battery, accumulator, AC, system DC, M Bus, or Fiber Optic driven
Type of storage; external EPROM or internal RAM
Type of Control needed for external applications, example: Remote applications
Vendor: feasibility, locality and availability of part in smaller quantities.

Table 50: The Microcontroller for this Project Requires the Following Capabilities at the Minimum:

Ultralow to low power consumption
Real time clock
Watchdog timer
I2C, UART
16 bit CPU
10kB RAM
Maximum speed 16MHz
High resolution timer 4ns

The big five in top of the list of microcontrollers manufacturers are Atmel(they build AVR, ARM and 8051), Intel that builds 8051 and 8052Basic, Freescale (Motorola) with his flash- based and/or HCS08 Series, Texas Instruments with the family of microcontrollers MSP430 (ultralow powered) and Silicon Labs with ARM Cortex microcontroller family. An additional company that initially targeted the student community is Microchip PIC microcontrollers with Small 6-pin chip STO23 to bigger packages up to 100 pin TQFPs.

For Atmel the most popular between AVR, ARM and 8051, AVR is a good choice microcontroller with a dedicated website AVRFreaks. The evaluation board is AVRbutterfly at an excellent price of $20. AVR is supported by GCC, giving a C compiler completely free. The AVRFreaks website has additional features and tools, for example a tool tree which includes the categories Assembler, compiler, computer utilities, debugger, design automation, development board, documents, emulator, programmer, programmer SW, Real Time OS, Reference Design and Simulator.

The 8051 from Intel was created long time ago but improvements were made with the 8052Basic by adding peripherals, increasing the memory, and lowering the power required. The Intel website itself it is not for student applications and it does not provide that much information, development tools or even a microcontroller with the minimum requirements for a small project like the energy metering node, Intel is more industrialized than the other manufacturers, although there is a dedicated website for the 8052 family at 8052.com but is not that helpful either.

Freescale has many popular families of microcontrollers but the most popular, also used in many schools to teach embedded systems, is the flash based 68HC908 series. Is not usual for Freescale to provide small quantities of chips, their main focus is in large industrialized quantities, but some of their parts could be bought at Digikey, Sparkfun and others. Freescale provides some microcontrollers that uses other types of architectures like von Neuman, not too popular or familiar in the field.

Texas Instruments in the other hand provides extremely low-power microcontrollers, the MSP430 series. Most of these chips are in SMT packages, but recently DIP packages have being introduced. They have a vast variety of 16-bit architectures and most importantly low cost USB development devices starting at $20. Many more varieties of microcontrollers with different features are portrayed in their website like the ARM cortex and C2000 32 bit microcontrollers. Not only Texas Instruments offer a vast amount of different microcontrollers, it offers development tools, training if desired and application resources. Also, Texas Instruments is a student friendly website with parts at a lower cost than for example Intel with their counterparts

.

Silicon Labs is a company located in California who is license to manufacture ARM microcontrollers. ARM is a true RISC architecture typically used in the mobile industry. They have lots of memory and a great performance, but their development environment lack the simplicity that other microcontrollers might offer. STM32 Cortex M3 chips are a good example of microcontrollers with good peripherals at a great price. Silicon Labs offers for their 32 bit microcontroller's software the usual IDE, software libraries and development kits in addition they have a unique feature the "Power Awake" system optimization tool.

Microchip PIC microcontrollers were one of the first ones to implement EEPROM and FLASH program memory, most of their microcontroller's uses the architecture Harvard with an accumulator based with the usual RAM sizes and program sizes. For the flash memory the pin count could go as low as 6 pin up to 100 pin. Some of their chips have DSP functionality and 16 bit ALU. One of the most popular is the Microchip PIC 32 with USB, CAN and Ethernet and a vast selection of user interface application to meet most designs. Some of the environments are consistent including development tools, MPLAB with a free integrated environment that includes a compiler. This development kits includes a free C compiler starting at $34.95 somewhat higher than AVR. The starter kits also include tutorial cd, starter board with an integrated programmer, debugger and optional I/O expansion boards. Microchip website has connections to a support link, a buy link, a sample link and a forum link. Now this microcontroller could simplify the design by integration with the aids of analog and digital peripheral like Ethernet, I2c, ADC, serial communication and USB Most of this companies offer smaller quantities of parts, low cost parts, locality of the company and availability of technical specification, information on possible application and finally an open source website. Texas Instruments, Silicon Labs, Microchip and Atmel are preferred manufacturers, among these ones there are a complete array of families of microcontrollers.

Using the selector available in their individual websites the election was reduce to one single component per manufacturer, table 51 establish a comparison between this selections to clearly visualize their advantages and disadvantages over each other.

Table 51: Microcontroller Comparison

Manufacturer	**Atmel**	**Microchip PIC**	**Freescale**	**Texas Instruments**
Manufacturer part #	ATSAM4L52CA-AU	PiC32MX120F032B	SPC5601PEF0MLH6	MSP430F6736
Image				
Availability	Immediate	In production	Available	Available
Unit price	$6.39	$1.71	$6.59	$3.25
Packaging	TQFP	SSOP,SOIC	LQFP64	LQFP
Series	SAM4L	PC132MX1	MPC564XA	MSP430
Core processor	ARMCortexM4	DMIPS16e	E200zoh	MSP430
Core Size	32 bits	32bits	32bits	16 bits
Speed	48MHz	50MHz	64MHz	25MHz
Connectivity	I2C,IrDA,LIN,SPI,UART/USART,USB	UART,SPI,I2C	CAN,LIN,SCI, SPI	I2C,IrDA,UART/USART,LIN,SPI
Digital communication Peripherals	Brown-out detect/Reset DMA,I2S	-------------	DMA,PWM, WDT	Brown-out, detect/reset, PWM
Comparator	1	3	1	0
Number of I/O	80	28	45	52
Program memory type	Flash	Flash	Flash	Flash
Program Memory size	128KB	32KB	192KB	128KB
RAM	32KB	8.192KB	12KB	8KB
Voltage Supply	1.68V-3.6V	2.3V-3.6V	3.3V-5V	1.8V-3.6V
Oscillator	Internal	Internal	Internal	Internal
Operating Temperature	-40°C to 85°C	-40°C to 85°C	-40°C to 85°C	-40°C to 85°C
ADC channel	3	10	12	8
Watchdog	1	1	1	1

The selected manufacturer is Texas Instruments for their availability of tools, aids, samples and examples that will help shape and develop a good design. Texas Instruments has many different families of microcontrollers, the MSP430 series exceed the parametric requirements for the design, also has typical applications that includes analog and digital sensor, digital timers and handheld meters. This microcontroller has a high performance with only a low power supply and this is key in the design of the smart meter. The device has the ability to enter different power modes (LPM) with a versatile clock system that could disable and enable different clocks and oscillators. The LPM applies as well to the different analog and digital peripherals. The Digital Control Oscillator (DCO) is fully programmable with a wake up time as low as 1μs, the RTC could be program to wake up and use the real time at specific intervals. Below is table 52 that helps in selecting the right microcontroller from the MSP430 family series.

Table 52: Family Series Comparison

Series	**Voltage**	**Value Line**	**4 Series**	**5 Series**	**6 Series**	**FRAM Series**	**RF SoC**
Part number prefix	L092	G2xxx	F2xx	F5xx	F6xx	FR5xxx	CC430
Max speed (MHz)	4	16	16	25	25	24	20
NVM (max KB)	0	56	120	512	512	64	32
SRAM (max KB)	2	4	8	66	67	2	4
GPIO	11	4-32	14-80	29-87	72-90	17-40	30-44
Comparator	Y	Y	Y	Y	Y	Y	Y
Timer	Y	Y	Y	Y	Y	Y	Y
ADC	Y	Y	Y	Y	Y	Y	Y
UART		Y	Y	Y	Y	Y	Y
I2C		Y	Y	Y	Y	Y	Y
SPI		Y	Y	Y	Y	Y	Y
Capacitive Touch		Y				Y	
Multiplier		Y	Y	Y	Y	Y	Y
DMA			Y	Y	Y	Y	Y
Op amps			Y	Y			
LCD			Y		Y		Y
RTC			Y	Y	Y	Y	Y
PMM				Y	Y	Y	Y
USB				Y	Y		
Hardware encryption (AES)					Y	Y	Y
FRAM						Y	
RF							Y

After comparing all the microcontrollers within the MSP430 family, the one that matches most of the requirements for the design is the 16 bit MSP430F6736 at a low price of $3.25, good size packaging and low input voltage requirements at a maximum of 3.6V.

Table 53.1: Pinout for the Microcontroller

Name	Pin Number	I/O	Description
SD0P0	1	I	SD24_B Positive Analog Input for converter 0
SD0N0	2	I	SD24_B Negative Analog Input for converter 0
SD1P0	3	I	SD24_B Positive Analog Input for converter 1
SD1N0	4	I	SD24_B Negative Analog Input for converter 1
SD2P0	5	I	SD24_B Positive Analog Input for converter 2
SD2N0	6	I	SD24_B Negative Analog Input for converter 2
VREF	7	I	SD24_B External reference voltage
AVSS	8		Analog ground supply
AVCC	9		Analog ground supply
VASYS	10		
P1.0/PM_TA0.0/VeREF-/A2	11	I/O	
P1.1/PM_TA0.1/VeREF+/A1	12	I/O	
P1.2/PM_UCA0RXD	13	I/O	
P1.3/PM_UCA0TXD	14	I/O	
AUXVCC2	15		
AUXVCC1	16		
VDSYS	17		
DVCC	18		Digital power supply
DVSS	19		Digital ground supply
VCORE	20		
XIN	21	I	Input terminal for crystal oscillator
XOUT	22	O	Output terminal for crystal oscillator
AUXVCC3	23		
P1.4/PM_UCA1RXD/	24	I/O	
P1.5/PM_UCA1TXD	25	I/O	
LCDCAP/R33	26	I/O	
COM0	27	O	LCD common output COM0 for LCD backplane
COM1	28	O	LCD common output COM1 for LCD backplane
COM2	29	O	LCD common output COM2 for LCD backplane
COM3	30	O	LCD common output COM3 for LCD backplane

Table 53.2: Pinout for the Microcontroller

Name	Pin Number	I/O	Description
P1.6/PM_UCA0CLK/COM4	31	I/O	
P1.7/PM_UCB0CLK/COM5	32	I/O	
P2.0/PM_UCB0SOMI	33	I/O	
P2.1/PM_UCB0SIMO/	34	I/O	
P2.2/PM_UCA2RXD	35	I/O	
P2.3/PM_UCA2TXD	36	I/O	
P2.4/PM_UCA1CLK/S35	37	I/O	
P2.5/PM_UCA2CLK/S34	38	I/O	
P2.6/PM_TA1.0/S33	39	I/O	
P2.7/PM_TA1.1/S32	40	I/O	
P3.0/PM_TA2.0/S31/BSL_TX	41	I/O	
P3.1/PM_TA2.1/S30/BSL_RX	42	I/O	
P3.2/PM_TACLK/PM_RTCCLK	43	I/O	
P3.3/PM_TA0.2/S28	44	I/O	
P3.4/PM_SDCLK/S27	45	I/O	
P3.5/PM_SD0DIO/S26	46	I/O	
P3.6/PM_SD1DIO/S25	47	I/O	
P3.7/PM_SD2DIO/S24	48	I/O	
P4.0/S23	49	I/O	
P4.1/S22	50	I/O	
P4.2/S21	51	I/O	
P4.3/S20	52	I/O	
P4.4/S19	53	I/O	
P4.5/S18	54	I/O	
P4.6/S17	55	I/O	
P4.7/S16	56	I/O	
P5.0/S15	57	I/O	
P5.1/S14	58	I/O	
DVSYS	59		
DVSS	60		
P5.2/S13	61	I/O	
P5.3/S12	62	I/O	
P5.4/S11	63	I/O	
P5.5/S10	64	I/O	
P5.6/S9	65	I/O	
P5.7/S8	66	I/O	
P6.0/S7	67	I/O	
P6.1/S6	68	I/O	
P6.2/S5	69	I/O	
P6.3/S4	70	I/O	
P6.4/S3	71	I/O	
P6.5/S2	72	I/O	
P6.6/S1	73	I/O	

Table 53.3: Pinout for the Microcontroller

Name	Pin Number	I/O	Description
P6.7/S0	74	I/O	
TEST/SBWTCK	75	I	
PJ.0/SMCLK/TDO	76	I/O	
PJ.1/MCLK/TDI/TCLK	77	I/O	
PJ.2/ADC10CLK/TMS	78	I/O	
PJ.3/ACLK/TCK	79	I/O	
RST/NMI/SBWTDIO	80	I/O	

Next, three items need to be considered: Evaluation kits, development and software tools. There are many different evaluation boards that meet different needs, for example MSP430 Launch Pad, ez430 Development kit, kits on experimenter and target boards and debugging and programming interfaces. Development Tools like basic Energia, modkit for starters and a more pro-software for professional development includes: Code Composer Studio IDE, IAR embedded Workbench and Open source MSPGCC. Software from Code generation tools to high level driver libraries which includes Grace (GUI-based Peripheral), specific application software; USB developer's Package, Real time Operating System (RTOS) and a Math Library. Programming Tools includes a Bootstrap Loader and Debug Stack.

Development Tools and Evaluation kits for MSP430F5438

Several selections exist for a development board for the MSP430F5438, many of them features a 100 pin socket that is compatible with other devices with similar pin count. The development board allows for quick application changes and upgrades in applications in wireless sensing and AMI. They include code examples, a technical support system and a developer community at 43oh.com. An example of a development tool is the LaunchPad. The LaunchPad is an inexpensive evaluation board that provides hardware and software reference design to explore applications such as wireless sensing.
Below table 54 compares different evaluation kits for MSP430F5438, the table includes the TI part number, a brief description and the cost of the evaluation kit.

Table 54: Comparison of Development Tools

Part Number	Description	Cost	Features
430 BOOST-CC110L	A low power wireless transceiver extension Kit	$19.00	CC110L MSP430G2553
MS EXP 430F5529LP	Integrated USB 2.0 enable MSP430F5529	$12.99	MSP430F5529 TPS2041B
MSP-EXP430G2	Launch Pad Value Line Development Kit with built in flash emulation	$9.99	MSP430G2211 MSP430G2231
430BOOST SENSE1	Capacitive touch, proximity sensor on board LED's	$10	MSP430G2452

Experimenter Boards

Experimenter Boards includes hardware components with the purpose to evaluate a full prototype system. The device includes code, schematics and examples with the main purpose to test the capabilities of the microcontroller.

Also, next table 55 shows the comparison between different experimenter boards targeted to the MSP430FR5739.

Table 55: Experimenter Boards Comparison

Part Number	Description	Cost
MSP-EXP430F5529	Complete USB development board that includes a microSD card, RF module connectors and integrated flash emulation tool	$149
MSP-EXPCC430RFX	Base board with a Rx satellite board	$149
MSP-EXP430FR5739	FRAM based experimenter board that includes an RF module	$35

Software Development Tools

The MSP430FR5739 as most of the MSP430 features several unique software development tools including: the ULP (ultra-low Power) Advisor, CAPSENSELIBRARY (Capacitive Touch Software Library), SAH-256 Secure Hash Standard, AES-128 Advanced Encryption Standard and others more detail and advanced software for platform development.

The ULP guides through a development that is energy efficient, applying the low powering features of the MSP430 microcontrollers by checking the code against the program that contains a ULP checklist that aims to used up the application with less energy (in the nano ampere scale). The ULP applies to all MSP430 microcontrollers.
CAPSENSELIBRARY includes a set of high level functions that are able to interconnect capacitive touch elements and sensors. Includes a C library as well as considerations and guidelines for hardware design.

The SAH-256 develops hash functions, taking blocks of data to return a fixed bit size, features Input 512 bit blocks, an output 256 bit hash. For the purpose of this design, the smart meter, this tool is not applicable because it deviates from the purpose and scope of the project, saving energy and at this point the security is not a relevant issue but it could potentially become necessary as this device becomes popular.

AES-128 has a similar purpose as the SAH-256, security, instead this time the software uses symmetric key algorithm to block cipher input blocks as big as 128 bits and output blocks of 128 bits blocks, in addition it features a Pure c library.

Another software tools worth mentioning are libraries like MSP430WARE, Math and Graphics; Application Software and Frameworks like Touch power Design GUI, Touch Pro GUI.

Out of all these helpful tools the most important and applicable to the main scope of the design is the ULP, saving even more energy when measuring the current and voltage of the household. Math, Graphics and MSP430WARE which is a collection of code examples and datasheets available for all MSP430 microcontrollers. It includes a Driver Library making it easier to communicate to a MSP430 microcontroller. The MSP430WARE is available in a compose code or as standalone package.

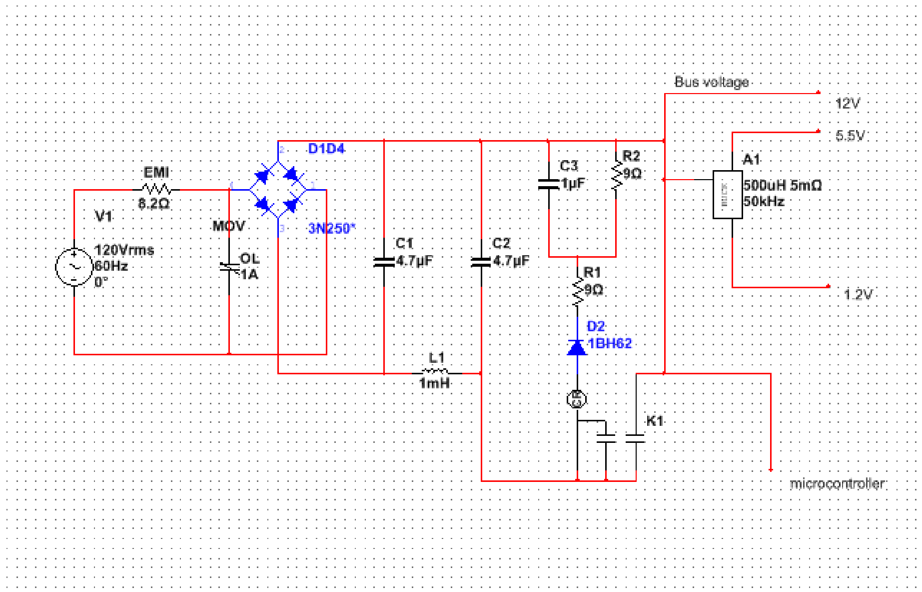


Figure 14: Schematics for the Power Supply of the Satellite Monitoring Node

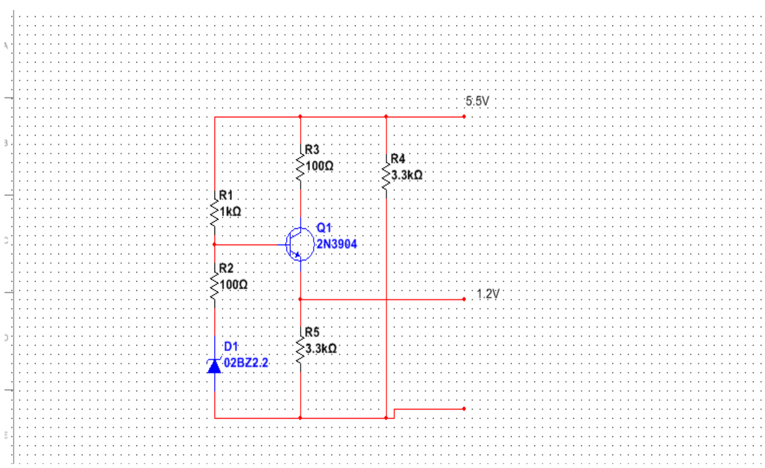


Figure 15: Voltage Divider for 1.2V & 5.5V

9.0 Project Prototype Construction and Coding

After having discussed all the parts and codes we can now finally construct a prototype and integrate the coding onto this prototype. In this section we will have the parts and discuss what PCB vendor we are going to use by looking at a lot of different PCB vendor. We even consider making our own PCB.

9.1 Part Acquisitions and BOM

Table 56.1: BOM

Item	Qty	Reference	Description	P/N	Manufacturer	Cost / per unit	Total
1	4	MOV	Surge protection	07D180k	Bourns Inc.	0.25	1.00
2	4	EMI	EMI protection	ESD3V3U1U-02LRHE63271N DKR-ND	Infineon technologies	0.48	1.92
3	2	BAT	9V battery	LA522	Energizer	2.38	4.76
4	2	MSP	16 bit microcontroller	MSP430F6736	TI	3.25	6.5
5	1	Dev	Development board	MSP-EXP430G2	TI	9.99	9.99
6	2	C1,C2	CAP CER 4.7uF 16 V 10 % radial	FK24X5R1E475K	TDK cop	0.45	.90
7	4	D1-D4	Gral. purpose diode 1000V/1A	1N4007-T	Diodes Inc.	0.13	0.52
8	2	L1	1mH, +/-5% RF coated	77F102T-TR-RC	Bourns Inc.	0.08	.016
9	1	RY	12VDC Relay	5-1462033-4	TE connectivity	4.01	4.01
10	1	S	Current shunt monitor	INA226	TI	1.40	1.40
11	1	P	Nema 5-15R/LS-30P Plug	------------------		13.61	13.61
12	1	PCB	PCB Board 60 sq. inch kit (mask)	Individual Orders	Advanced Circuit	$50	$50

Table 56.2: BOM

Item	Qty	Reference	Description	P/N	Manufacturer	Cost / per unit	Total
13	1	PCB	PCB Board 30 sq. inch	Individual Orders	Advanced Circuit	$33	$33
14	1	PTH	1.2 to 5.5V Non-isolated Wide Adjust module	PTH12050W	TI	6.90	6.90
15	2	EN	Metal enclosure	PRT-11735	Sparkfun	4.95	9.90
16	1	Z1	Zener diode	1N4007GP	Microcommerce co.	0.25	0.25
17	1	C4	10nF Capacitor	COM08982	Sparkfun	0.35	0.35
18	1	C5	100nF Capacitor	COM08983	Sparkfun	0.40	0.40
19	1	R1	100Ω 0.25W 1%Resistor	WHA100FET	Ohmite	0.93	0.93
20	1	R2	1kΩ 0.25W 1% Resistor	WHA150FET	Ohmite	1.95/50	1.95
21	1	R3	150kΩ 0.25W 5% Resistor	CF14J150K	Ohmite	0.08	0.08

9.2 PCB Vendor and Assembly

We will look at various PCB vendors to find out which one provides the best service, the cheapest prices, the highest quality, and the fastest shipping. There are a lot of vendors out there and as we look at their websites we not only learn about the vendors themselves but also learn more about PCB and its different limitations and usefulness and how to maximize the boards use with the money we have spent. We will look at vendors like Advanced Circuits, Alberta Printed Circuits, E-TekNet, Gold Phoenix, Olimex, OURPCB, PCBCART, Sunstone, and Sierra Circuits. It is very important that we get the best deal possible and the highest quality possible and that is why we are doing an intensive research for vendors as the whole base of our project lies in the PCB. In case we decide to make out own printed circuit board which is also a possibility we discuss this possibility in the last part of this section.

9.2.1 Advanced Circuits

This Company provides a variety of options for affordable printed circuit boards. They provide a variety of services and different shipping options including an option where they ship your printed circuit board the next day but without the solder mask. There is also a special from this website for students where you can get a 60 square inch board for $33 and it includes the soldering mask and the top silkscreen. If we include the shipping it will be a total of $50. So this company seems pretty promising for students. The interface for ordering is pretty easy as well as student may use the PCB Artist which is PCB layout software to create the layout of the printed circuit board for free and simply upload the file to the website and then it will calculate the price per unit for you. The website also accepts the Gerber files for the design. There is also a $66 for a 4 layer PCB option. There are limitations as to how many can be bought and to the minimum number of units that can be bought but for our project this will most likely not be an issue.

Table 57: PCB Comparisons:

Specifications	For the $33 each student deal	For the $66 each student deal
Minimum Board Quantity	4	4
Lead Time	5 days	5 days
Lead Free Solder Finish	Yes	Yes
Minimum line per space	0.006 inch	0.006 inch
Minimum hole size	0.015 inch	0.015 inch
All Holes Plated	Yes	Yes
Green LPI Mask	Yes	Yes
White Legend	1 or 2 sides	1 or 2 sides
Part number per order	1 part	1 part
Multiple part fee	$50	$50
Maximum size	60 square inches	30 square inches
Slots or overlapping drill hits	No	No
Internal Routing	No	No
Routed to Overall Dimension	Yes	Yes
Maximum Holes per Square Inch	35	35

9.2.2 Alberta Printed Circuits

This Company gives a lot of variety in prices depending on what you plan to be using. However the drill sizes seem to have a lot of constraints. There are only 10 free drill sizes and for each additional drill size required that is not part of the free drills there is an additional premium of roughly 1 to 2 dollars. If we don’t use any free drills we are better off with using Advanced Circuits to print our circuit boards seeing that it would cost a lot more just for the circuit alone. Since this company does not have a student deal, the prices for the printed circuit board are in general much more expensive than the student pricing for the Advanced Circuit Company.

9.2.3 E-TekNet
A company that has its manufacturing factories are located in china but the headquarters is located in Arizona. This allows for some extremely cheap printed circuit boards. However there are some issues with the quality and the shipping will most likely have delays which for our project, we cannot take a risk with quality nor shipping delay as the time frame in which we need the complete this project is extremely limited. For this reason we will most likely avoid this printed circuit board company entirely to avoid any risk that comes with tardiness and poor quality.

9.2.4 Gold Phoenix
Even though this company provides cheap printed circuit board service, it still does not beat the price compared with the Advanced Circuit website. The advantage of this company is that it has a lot of options as well on everything from the thickness to the amount of layers and shipping options and even in the masking and finishing. However this company only sells in large amounts the smallest being 100 square inches. Seeing that we do need PCB for the central hub and for each of the satellite stations this option might be just what we need for our project as we can have multiple designs on one board and panel them.

9.2.5 Olimex
This company produces cheap PCB at great quality. However, due to a setback in their production line, this service has been temporary disabled. Another problem is their location in Bulgaria which will cause a greater delay in trying to get to them or from them. If this service does get back on as they are planning to do, we might be able to use this company as it provides a lot of the services that these other companies provide, but they do not charge extra for it like masking, paneling, having multiple boards on the same panel, etc. We have some of their specifications below in table 58 as well.

Table 58.1: Double Side DSS/DSQ PCB Panel Specifications

Panel sizes:	DSS 160x100 mm (6.3 x 3.9"), DSQ 320x200 mm (12.6 x 7.8")
Laminate type	FR-4
Laminate thickness	0.5 mm, 0.8 mm, 1.0 mm, 1.5 mm (standard)
Laminate base copper thickness	18/18 um (1/2 oz), 35/35 um (1 oz) (standard)
Solder mask	double side liquid photoimagable (LPI) green color
Component print	single side white color ink
Minimum tracks and spaces	0,203 mm (0,008")

Table 58.2: Double Side DSS/DSQ PCB Panel Specifications

Standard drill tools	0,7 mm (0,028"), 0,9 mm (0,035"), 1.0 mm (0,039"), 1.1 mm (0,043"), 1.3 mm (0,051"), 1.5 mm (0,059"), 2.1 mm (0,083"), 3.3 mm (0,13")
Number of drill holes	up to 500 for DSS, up to 2000 for DSQ
PCB finish:	immersion gold ENIG ROHS compliant
De-panelization	cut-to-border only in rectangle shapes
Turnaround time	3-5 Working days

9.2.6 OurPCB

This company has similar quality as Golden Phoenix. The price is not bad either. Using the price calculator we have noticed that the larger the board you buy, the cheaper the price per square inch becomes. This factory is also located in China so the shipping will also take a while to get here. Here is a list of this company's capability.

Table 59: OurPCB Capabilities:

Material	FR4, High TG FR4，Halogen Free material,CEM-3, Rogers HF material, etc.
Layer counts	2-36 layers
Finished Copper Thickness	0.5-5 OZ
Finished Board Thickness	0.2-6.0mm
Minimum Line/Track Width	4mil
Minimum Line/Track Space	4mil
Minimum Contour Tolerance	+/-0.1mm
Minimum Finished Diameter of PTH Hole	0.1mm
Max. Board Thickness/Hole Ratio	12:1
Minimum Solder Mask Bridge	4mil (Minimum SMT Pad Space 8mil)
Minimum Legend(Silkscreen) Track Width	5mil
Minimum Legend(Silkscreen) Height	30mil
Minimum drilling slot size	0.6mm
Solder mask color	green, black, blue, white, yellow, and matt, etc.
Solder mask hardness	6H
Legend/Silkscreen Color	white, yellow, black, etc.

9.2.7 PCBCART

The quality of the product this company produces is also very good compared to that of Advanced Circuits. The price is similar to the rest of the prices of the other vendors that don't have the student special. The best price so far is still advanced circuits since they have the student special. Other than that, the price is fair and the capabilities are from high standards and quality as we can see from table 60 below.

Table 60: PCBCART Capabilities:

Layers	1-10 layers
Material	FR4
Copper Thickness	1/2 to 6oz (18um-210um)
Board Thickness	.016-.126" (0.4mm-3.2mm)
Surface finish	HASL,Ni/Au,OSP
Soldermask	LPI, different colors
Board Dimension	600x700mm
Min Hole Diameter	6mil (0.15mm)
Min line width	4mil (0.1mm)
Min line spacing	4mil (0.1mm)
Min SMT pitch	8mil (0.2mm)
Min. width of slots	0.8mm
Max. thickness of Au in ENIG	3-5micro inches
Surface/hole plating	ave. 25um min. 20um
Tolerance:	
Hole Tolerance	+/-003"(+/-0.08mm)~+/-.006"(+/-0.15mm)
Thickness Tolerance	+/-.004" (+/-0.1mm)~+/-10%
Copper Thickness Tolerance	-0um+20um
SM Tolerance (LPI)	.003"(0.075mm)
Dimension Tolerance	.004"(0.1mm)~0.012"(0.3mm)

9.2.8 Sunstone Circuits

Sunstone will come in handy if our final design suddenly decides not to work and we need only one or two small printed circuit board to replace the one that is either damaged or had a mistake on it. The company allows the order of small amount of PCB for a low price and a pretty fast lead time. Since this company is located in Oregon here in the United States, the shipping will be much faster as well.

9.2.9 Sierra Circuits

This is the company with probably the highest quality of printed circuit board. They have a special price for new customers as well as a no touch prototype special that allows us to buy up to 100 square inches of PCB for a very low price. It even includes unlimited amount of drill in the standard sizes, the mask and the silkscreen.

Table 61.1: Sierra Circuits Capabilities:

Min Layer count	1
Max Layer Count	24
Min Board Thickness	.010"
Max Board Thickness	.200"
Min Core Thickness	.002"
Min Dielectric	.002"
Min. Starting Copper Foil Weight	9 micron

Table 61: Sierra Circuits Capabilities:

Max. Finished Copper Thickness (O/L)	6 oz
Max. Finished Copper Thickness (I/L)	4 oz
Maximum Panel Size	21" x 29"
Minimum Panel Size	12" x 18"
Smallest Mech Drill Diameter	.0059"
Smallest Laser Drill Diameter	.0030" / .0080"
Min Finished Hole Size	.004"
Max Thru Hole Aspect Ratio	10:1
Max Blind Via Aspect Ratio	.75:1
Blind Via Finished Hole Size	.004"
Buried Via Finished Hole Size	.004"
Min LW/LS (mils)	.003"
Min Pad Size for test	.005"
Process Pad Diameter	D + .012" (1 mil annular ring)
Stacked vias	Yes

9.2.10 Home Made PCB

This one requires some additional work from the group but it comes with the benefit that we save money and we gain experience in printing our own circuit boards. It is not hard to come across a laser printer or any high dots per inch printer and get our hands on, copper clad boards, an iron or other heating element, a drill, and the chemicals needed to print and make our own circuit boards at home. There are a lot of instructional videos as well as helpful forums that can guide us into making our own printed circuit board. Since all of the chemicals used in the process are reusable and the cost of the copper clad boards are extremely cheap and the paper used for printing is also super cheap, home printing of the circuit board is definitely the most inexpensive way to go. Not only is it inexpensive but it can be done in only a couple of hours so it is also the fastest way to get the printed circuit board. We are not even limited to 1 layer since there are instructions for 2 layers PCB and even with masking. And from 2 layer PCB to multi layer PCB it is not that hard either even though we do not believe we need more than 2 layers of PCB. The only limitation at this moment is that none of our group members have any experience in printing our own circuit boards. This means that the making of the PCB will be a completely new experience and that the first couple of PCB made will be almost entirely experimental and would probably not even be used in the actual design. If we do decide to go the home made PCB way it would mean that we will no longer be limited by the vendors limitation and size is no longer an issue as we can produce any small quantity or large quantity and we can use our own drill size. We even save time since we do not need to wait for any shipment to arrive and the time it takes these companies to make these PCB can be days while we can print our own circuits in a day or less. The disadvantage of Home printing the PCB is the quality. With printing errors or etching parts that were not meant to be etched or even having contaminants contaminating the board will result in a poor PCB and we might end up with a flawed PCB that either does not work as intended or does not work at all. If however we manage to make the highest quality possible for homemade PCB then this is a viable option for our project as it is not impossible to do and it can save a lot of time and money at the cost of hands on work and unprofessional quality.

10.0 Project Prototype Testing

We plan to rigorously test all testable aspects of our project to ensure we don't miss anything no matter how small and insignificant it may seem with the exception to this being the MVO surge protectors which we will assume work as intended. We plan to test each of the hardware components each individually, and then as a system as we build up to the final finished prototype. This will allow us to hopefully catch and replace any faulty parts as well as catch and fix any coding or logic errors that we may have in our project. We plan to continue testing though the entire project to ensure everything is working as expected. This should make it so that any errors we do find we are able to catch quickly and fix them with minimal troubleshooting as they should be as a result of the most recent part we have added on to our project. This while time consuming should take less time over all as we will not have to spend very much time hunting down and trying to figure out what caused any unexpected behavior or errors that we encounter along the way.

Once we have our prototype built and working we will then be able to repeat all of our tests again as well as some extra tests to help us ensure that we don't have any problems either logical or coding in our project. We can at that time begin doing some standard tests with light bulbs and only one or two satellite monitoring stations active at a time and work our way up to all five satellite monitoring stations active at once.

Testing Efficiency within the satellite monitoring node

Accuracy of Pin and Pout are measure specifically Vin, Vout and Iin and Iout. The points where to measure them, what input voltage and what output load should be at that place.

Three input voltage levels will be taken, at a regular average level, somewhat above it and somewhat below it to discover behaviors at extreme levels. For example we could choose 15A as a load input current since this value is right at the limit of what the power supply can handle it could show us any problems with current limiting and instability. Later, 8 to 10 steps are taken keeping the same input voltage but decreasing the current load by 2 A until 0.5A more or less. After all the values are taken we will graph the efficiency, this will clearly reveal any issues in the design.

Table 62.1: Testing Efficiency Within the Satellite Monitoring Node

Trial number	Vin(V)	Iload(A)	Vout(V)	Iout(A)	Pin(W)	Pout(W)	%Efficiency
1	12 V	15 A					
2	12 V	13 A					
3	12 V	12 A					
4	12 V	10 A					
5	12 V	8 A					
6	12 V	6 A					
7	12 V	3 A					

Table 62.2: Testing Efficiency Within the Satellite Monitoring Node

8	12 V	1 A					
9	12 V	0.5 A					
10	12 V	0.2 A					
1	9 V	15 A					
2	9 V	13 A					
3	9 V	12 A					
4	9 V	10 A					
5	9 V	8 A					
6	9 V	6 A					
7	9 V	3 A					
8	9 V	1 A					
9	9 V	0.5 A					
10	9 V	0.2 A					
1	6 V	15 A					
2	6 V	13 A					
3	6 V	12 A					
4	6 V	10 A					
5	6 V	8 A					
6	6 V	6 A					
7	6 V	3 A					
8	6 V	1 A					
9	6 V	0.5 A					
10	6 V	0.2 A					

Noise testing at the satellite monitoring nodes

This test is to determine the presence of switching ripple noise and transient noise using an appropriate probing technique in other words we will be using a short wire or spring coming out of the testing probe instead of a ground wire to reduce more noise interference. The probe will be place right at the output capacitor of the voltage regulator and before the shunt current monitor, right across it, using the oscilloscope we place a bandwidth limiting below 100 MHz, and by placing the cursor right at the top and bottom of the waveform we will measure the voltage difference and the frequency of the noise, if it is too high more into 100 MHz value, that is an indication that we need to place decoupling capacitors to reduce the noise.

Table 63.1: Noise Testing at the Satellite Monitoring Nodes

	Switching ripple noise		**Transient Noise**	
Iout(load)	**Voltage (mV) noise**	**Frequency**	**Voltage (mV) noise**	**Frequency**
15 A				
15 A				
15 A				

Table 63.2: Noise Testing at the Satellite Monitoring Nodes

	Switching ripple noise		Transient Noise	
Iout(load)	**Voltage (mV) noise**	**Frequency**	**Voltage (mV) noise**	**Frequency**
15 A				
15 A				
15 A				
15 A				
15 A				
15 A				
15 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				

Noise testing at the hub node
Same as the satellite measurement node, right after the AC/DC voltage converter and right after the conditioning of the circuitry

Table 64.1: Noise Testing at the Hub Node

	Switching ripple noise		Transient Noise	
Iout(load)	**Voltage Delta (mV) noise**	**Frequency**	**Voltage Delta (mV) noise**	**Frequency**
15 A				
15 A				
15 A				

Table 64.2: Noise Testing at the Hub Node

	Switching ripple noise		Transient Noise	
Iout(load)	**Voltage Delta (mV) noise**	**Frequency**	**Voltage Delta (mV) noise**	**Frequency**
15 A				
15 A				
15 A				
15 A				
15 A				
15 A				
15 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
10 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				
5 A				

Measuring the stability of the system

It is very important to consider stability when designing and testing a system. Stability inform us how the system reacts to load changes, how to maintain proper output margin between the feedback and the amplifier of the regulation part, that it does not go in phase with the input, the amount of phase difference is important. A small resistor of 10 to 15 Ω at will be at the top side of the network at the feedback network of the regulator. The test is perform at different operating conditions, at nominal, minimum and maximum of input operating voltage and current load.

Table 65: Measuring System Stability

Vin(V)	I load(A)	Magnitude	Phase	Phase difference
10 V	0			
10 V	2			
10 V	8			
10 V	12			
10 V	25			
12 V	0			
12 V	2			
12 V	8			
12 V	12			
12 V	25			
15 V	0			
15 V	2			
15 V	8			
15 V	12			
15 V	25			

The magnitude where is passes zero move up to the phase and the delta between this two, and at different operating conditions the gain and phase margin should stay the same or as close as possible

Testing error and accuracy when using the current shunt monitor
The percentage of error testing is based on measurements taken right after the shunt the shunt using a regular Multi-meter.

Table 66: Output Percentage Error

	Multi-meter measurements			Current Shunt monitor measurements			Output % Error
Load	**Current**	**Voltage**	**Power**	**Current**	**Voltage**	**Power**	
Light bulb							
Laptop							
Cell phone							

Table 67.1: Percentage Accuracy of Measurements from INA 194[xxxiii]

Case	Output % Error (Table X)	(Vin+)-Vin_	Vcm Common Mode	Vs Voltage relative to PS	% Accuracy
(Vin+)- Vin_>=20mV Vcm>=Vs					

Table 67.2: Percentage Accuracy of Measurements from INA 194[xxxiv]

Case	Output % Error (Table X)	(Vin+)-Vin_	Vcm Common Mode	Vs Voltage relative to PS	% Accuracy
(Vin+)-Vin_>=20mV Vcm<Vs					
(Vin+)-Vin<=20mV -16V<=Vcm<0					
(Vin+)-Vin<20mV 0V<=Vcm<=Vs					
(Vin+)-Vin_<20mV Vs<Vcm<=80V					

Test P1 – Test P48: Prototype testing

1. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring station 1
2. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring station 1
3. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring station 1
4. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring station 1
5. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring station 1
6. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring station 2
7. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring station 2
8. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring station 2
9. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring station 2
10. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring station 2
11. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring station 3
12. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring station 3

13. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring station 3
14. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring station 3
15. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring station 3
16. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring station 4
17. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring station 4
18. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring station 4
19. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring station 4
20. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring station 4
21. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring station 5
22. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring station 5
23. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring station 5
24. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring station 5
25. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring station 5
26. Does the correct power usage register with 1 60 watt light bulb in satellite monitoring stations 1, 2, 3, 4 and 5
27. Does the correct power usage register with 2 60 watt light bulbs in satellite monitoring stations 1, 2, 3, 4 and 5
28. Does the correct power usage register with 3 60 watt light bulbs in satellite monitoring stations 1, 2, 3, 4 and 5
29. Does the correct power usage register with 4 60 watt light bulbs in satellite monitoring stations 1, 2, 3, 4 and 5
30. Does the correct power usage register with 5 60 watt light bulbs in satellite monitoring stations 1, 2, 3, 4 and 5
31. Does the correct power usage register with 1 small personal fan in satellite monitoring station 1
32. Does the correct power usage register with 2 small personal fan in satellite monitoring station 1
33. Does the correct power usage register with 3 small personal fan in satellite monitoring station 1
34. Does the correct power usage register with 1 small personal fan in satellite monitoring station 2
35. Does the correct power usage register with 2 small personal fan in satellite monitoring station 2

36. Does the correct power usage register with 3 small personal fan in satellite monitoring station 2
37. Does the correct power usage register with 1 small personal fan in satellite monitoring station 3
38. Does the correct power usage register with 2 small personal fan in satellite monitoring station 3
39. Does the correct power usage register with 3 small personal fan in satellite monitoring station 3
40. Does the correct power usage register with 1 small personal fan in satellite monitoring station 4
41. Does the correct power usage register with 2 small personal fan in satellite monitoring station 4
42. Does the correct power usage register with 3 small personal fan in satellite monitoring station 4
43. Does the correct power usage register with 1 small personal fan in satellite monitoring station 5
44. Does the correct power usage register with 2 small personal fan in satellite monitoring station 5
45. Does the correct power usage register with 3 small personal fan in satellite monitoring station 5
46. Does the correct power usage register with 1 small personal fan in satellite monitoring stations 1, 2, 3, 4 and 5
47. Does the correct power usage register with 2 small personal fan in satellite monitoring stations 1, 2, 3, 4 and 5
48. Does the correct power usage register with 3 small personal fan in satellite monitoring stations 1, 2, 3, 4 and 5

Table 68.1: Prototype Test Results

Test	Result	Tester	Notes
Test P1			
Test P2			
Test P3			
Test P4			
Test P5			
Test P6			
Test P7			
Test P8			
Test P9			
Test P10			
Test P11			
Test P12			
Test P13			
Test P14			
Test P15			
Test P16			
Test P17			

Table 68.2: Prototype Test Results

Test	Result	Tester	Notes
Test P18			
Test P19			
Test P20			
Test P21			
Test P22			
Test P23			
Test P24			
Test P25			
Test P26			
Test P27			
Test P28			
Test P29			
Test P30			
Test P31			
Test P32			
Test P33			
Test P34			
Test P35			
Test P36			
Test P37			
Test P38			
Test P39			
Test P40			
Test P41			
Test P42			
Test P43			
Test P44			
Test P45			
Test P46			
Test P47			
Test P48			
Test P49			

10.1 Hardware Test Environment

For our hardware testing we will be testing most of the items ourselves. We will not be testing the surge protectors however. The reason for this is that to rent the machine to test them cost over $1000 dollars, and when I went to speak with Dr. Richie about it he said we didn't need to test known and tested parts like surge protectors. We plan to test the components when we can when we get them before we connect them to anything to make sure we didn't get a faulty component. After that we plan to connect them and then test the new system as a whole to make sure we have properly connected them to one another.

We will do all of these tests at room temperature between 60 degrees Fahrenheit and 90 degrees Fahrenheit. These tests will also all be done indoors where the relative humidity is under 70 percent. This will allow us to better control the number of variables we have to deal with. This will also allow us an easy way to repeat any and all tests multiple times with nearly the identical environmental settings. We plan to run all of the tests ourselves as well so as to remove the factor of other people doing the tests a different way.

10.2 Hardware Specific Testing

With the microcontroller working which will be the brains of the device we can now shift our focus to the remainder of the devices physical components. We will have to interface the microcontroller with the printed circuit board as well as the CT current sensor, MOV surge protector, Bluetooth device and relay.

We will then add the AC-AC adapter which doesn't need to interact with the microcontroller at all to the design. This will in turn connect to the voltage regulator which also doesn't need to be connected to the microcontroller at all. These components will then be connected to the surge protector and the CT current sensor.

Test H1 – Test H8: Hardware testing

1. Does the microcontroller turn on
2. Does the CT current sensor turn on
3. Does the Bluetooth device turn on
4. Does the relay turn on
5. Does the relay turn off
6. Does the surge protector accept power
7. Does the MOV accept power
8. Does AC-AC adapter accept power
9. Repeat tests 1 – 8 for each stations components

Table 69.1: Hardware Test Results

Test	Result	Tester	Notes
Test H1.1			
Test H2.1			
Test H3.1			
Test H4.1			
Test H5.1			
Test H6.1			
Test H7.1			
Test H8.1			
Test H1.2			

Table 69.2: Hardware Test Results

Test	Result	Tester	Notes
Test H2.2			
Test H3.2			
Test H4.2			
Test H5.2			
Test H6.2			
Test H7.2			
Test H8.2			
Test H1.3			
Test H2.3			
Test H3.3			
Test H4.3			
Test H5.3			
Test H6.3			
Test H7.3			
Test H8.3			
Test H1.4			
Test H2.4			
Test H3.4			
Test H4.4			
Test H5.4			
Test H6.4			
Test H7.4			
Test H8.4			
Test H1.5			
Test H2.5			
Test H3.5			
Test H4.5			
Test H5.5			
Test H6.5			
Test H7.5			
Test H8.5			

10.3 Satellite Monitoring Station Microcontroller Hardware and Software Testing

For our microcontroller hardware and software testing we plan we plan to do as many tests as we can think of to ensure that we find and fix as many bugs as possible that may exist in the program or the way the different parts are laid out as we don’t wish to have software with any bugs in it nor do we wish to damage any of the equipment that we are using.

We will first try to find and fix all of the critical errors which cause the software to crash, and that could potentially damage the microcontroller or some of the devices attached to it. We will then work on less critical bugs finding and fixing them to ensure that everything works the way it should. Once all of this is done we will then focus on fixing things that are not as crucial such as reducing the number of cycles required to do something as the fewer cycles it takes the faster it will work and the less energy it should use in turn as it will be done sooner.

We will next work on testing each of the different components that we will have attached to the microcontrollers with the microcontrollers interface. This will allow us to further calibrate the devices and verify that the microcontrollers are correctly interfacing with them.

This will be split into two different parts. The first part will be the microcontrollers in the satellite monitoring stations. These will need to interact with the devices in each station. They will have to correctly interface with them as well as correctly receive and translate the data they get from them and take the appropriate actions. This will require a number of tests to ensure that all of the hardware is working correctly with the microcontrollers. We also have to ensure that the microcontroller's software is correctly storing our data points, sending those data points via the Bluetooth controllers to the central hub, and then once it has been sent and verified deleting those sent data points to make room for more data points. Also we need to make sure that all of the analog to digital and digital to analog conversions are being correctly done and received or sent out.

We will do all of these tests at room temperature between 60 degrees Fahrenheit and 90 degrees Fahrenheit. These tests will also all be done indoors where the relative humidity is not too high. This will allow us to better control the number of variables we have to deal with. This will also allow us an easy way to repeat any and all tests multiple times with nearly the exact environmental settings. We plan to run all of the tests ourselves so as to remove the factor of other people doing the tests a different way.

10.4 Microcontroller Hardware and Software Specific Testing

We plan to test the microcontroller first when connected to a desktop or laptop to work out any bugs or errors in the code before testing it with the other components. We then plan to connect each of the components to the microcontroller one at a time and then test their interactions with the microcontroller and verify that they are interacting as we had anticipated. Once we have tested each of the components we will then connect two and then three till they are all connected to the microcontroller and test that they all still work as we have anticipated.

We will first interface the Bluetooth devices with the microcontroller. We will do this first as this is a crucial part of the design. Once we have the Bluetooth and microcontroller intergraded and working correctly we will at this point begin to test the Android application with the Bluetooth devices and the microcontroller to send and receive data. Once they are working at a satisfactory level we will then work on setting up a mesh network with the Bluetooth devices. This will allow for a reliable and robust network for our data to travel over as well as for a way to let us know if a device goes offline or a new device comes online.

Next we will interface the relays with the microcontroller. These will be used to turn a device off and prevent phantom energy drain when not in use as well as turn the device back on when it is needed again. We will have to test that the relays can be both turned off and then back on again using the microcontrollers to control them. We will have to test that when in the on position if we tell them to turn on again that they will remain on without any interruptions in power. We will also have to verify that if they are off and we tell them to turn off that they remain in the off position and don't turn on and then off again as that could be damaging to certain items. We will also need to verify that our counter for them is working correctly and that they can't be turned off and on right away. We plan to have a 5 minute or 300 second delay coded in so as to not damage any items that they are connected to.

Then we will interface the CT current sensor with the microcontroller. This is a very important part of the device as this will be what allows us to monitor that current usage of the device. Once we have connected the CT current sensor with the microcontroller we will test it with known currents and voltages. We will use a multi-meter to further verify the readings. We will then calibrate the output from the CT current sensor to work with the microcontroller. Once we have done this we will make sure that the microcontroller is receiving and interpreting the input from the CT current sensor correctly and storing it onto the microcontroller for transmission to the central hub. We are planning to have the CT current sensors input be saved every one second. This will allow us to calculate the real and apparent power that is being used by the device.

Once those are working we will then add in the surge protector. We will need to verify that when it is tripped which can be simulated by removing it from the microcontroller that the pin it is connected to will change from high to low. This will cause the microcontroller to register a tripped circuit and relay that information over the Bluetooth mesh network back to the central hub as well as the Android application. This will alert the user that something is wrong and that they should inspect the tripped device for damage, fire or any other possible risks that could have come as a result of a surge of power flowing into the area.

Test S1 – Test S5: Satellite monitoring station integration testing

1. Does the microcontroller have power?
2. Does the microcontroller correctly interface with the CT current sensor
3. Does the microcontroller correctly interface with the Bluetooth device
4. Does the microcontroller correctly interface with the relay
5. Does the microcontroller correctly interface with the MOV surge protector

Test S6 – Test S19: Satellite monitoring station program PC based testing

6. Does the program once running allow you to sample dummy data from the CT current sensor once every second?
7. Does the program once running allow you to sample dummy data from the CT current sensor once every 5 seconds?
8. Does the program correctly allow you to store that dummy sampled data into a file?
9. Does the program correctly read the dummy sampled data from the file?
10. Does the program once running allow you to receive a dummy request to turn the relay on and power down a device?
11. Does the program once running allow you to power down a device by turning the relay on?
12. Does the program once a device has been powered down send a dummy notification to a dummy central hub letting it know the action has been completed?
13. Does the program once running allow you to receive a dummy request to turn the relay off and power up the device?
14. Does the program once running allow you to power up a device by turning the relay off?
15. Does the program once running allow you to set up a dummy mesh network?
16. Does the program correctly allow you to add a new satellite monitoring station to the dummy mesh network?
17. Does the program correctly allow you to remove an existing satellite monitoring station from the dummy mesh network?
18. Does the program correctly receive a dummy Bluetooth data request from a dummy central hub?
19. Does the program correctly allow you to send dummy Bluetooth data packets to a dummy central hub?

Test S20 – Test S35: Satellite monitoring station program real world testing

20. Does the program correctly receive a dummy Bluetooth data request from the central hub?
21. Does the program correctly allow you to send dummy Bluetooth data packets to the central hub?
22. Does the program once running allow you to sample data from the CT current sensor once every second?
23. Does the program once running allow you to sample data from the CT current sensor once every 5 seconds?
24. Does the program correctly allow you to store that sampled data into a file?
25. Does the program correctly read the sampled data from the file?
26. Does the program once running allow you to receive a request to turn the relay on and power down a device?
27. Does the program once running allow you to power down a device by turning the relay on?
28. Does the program once a device has been powered down send a notification to the central hub letting it know the action has been completed?

29. Does the program once running allow you to receive a request to turn the relay off and power up the device?
30. Does the program once running allow you to power up a device by turning the relay off?
31. Does the program once running allow you to set up a mesh network?
32. Does the program correctly allow you to add a new satellite monitoring station to the mesh network?
33. Does the program correctly allow you to remove an existing satellite monitoring station from the mesh network?
34. Does the program correctly receive a Bluetooth data request from the central hub?
35. Does the program correctly allow you to send Bluetooth data packets to the central hub?

Table 70.1: Satellite Monitoring Stations Test Results

Test	Result	Tester	Notes
Test S1			
Test S2			
Test S3			
Test S4			
Test S5			
Test S6			
Test S7			
Test S8			
Test S9			
Test S10			
Test S11			
Test S12			
Test S13			
Test S14			
Test S15			
Test S16			
Test S17			
Test S18			
Test S19			
Test S20			
Test S21			
Test S22			
Test S23			
Test S24			
Test S25			
Test S26			
Test S27			
Test S28			
Test S29			
Test S30			

Table 70.2: Satellite Monitoring Stations Test Results

Test	Result	Tester	Notes
Test S31			
Test S32			
Test S33			
Test S34			
Test S35			

10.5 Central Hub Microcontroller Hardware and Software Testing

For the microcontroller in our central hub we will have to do a different set of tests as it will not be connected to the different devices that the microcontrollers in our satellite monitoring stations will be. Also it will be the only microcontroller that is connected to the LCD touch screen display. In addition it will be the only one that is storing and refactoring the data over time to help reduce the space it will take up.

For our central hubs microcontroller and LCD we will first do all of the testing while connected to either a desktop or laptop. This will allow us to better alter the code in real time as well as use a number of debugging tools that will let us see exactly what is being sent to and from the microcontroller as well as what the value of each pin, register, and buffer on that microcontroller are at any given time.

First we will work on fixing any and all critical errors that cause the program to crash or that could potentially damage the microcontroller or the LCD touch screen display. Once we are satisfied that we have found and fixed any critical errors we will then work on finding and fixing less critical bugs to ensure that everything is working the way it should. These will more than likely be fixing interface, logic and semantic errors in the code. Finally we will work on fixing cosmetic errors and improving the functionality of the LCD touch screen display to allow the user to do and see more and more things with it. Once we are satisfied with how the program is working when connected to the desktop or laptop computer we will then disconnect it and rerun all of our tests again with it being self-contained.

Test M1 – Test M5: Central hub function & integration testing

1. Does the Date and Time class correctly compile?
2. Does the Bluetooth class correctly compile?
3. Does the Draw class correctly compile?
4. Does the Database class correctly compile?
5. Does the entire program compile without errors?

Test M6 – Test M40: Central hub testing

6. Does the program once compiled and running correctly display the date and time?
7. Does the program correctly allow you to rename a satellite monitoring station?

8. Does the program correctly allow you to add a new satellite monitoring station?
9. Does the program correctly allow you to remove an existing satellite monitoring station?
10. Does the program correctly allow you to display information from a single dummy satellite monitoring station as a table?
11. Does the program correctly allow you to display information from a single dummy satellite monitoring station as a graph?
12. Does the program correctly allow you to display information from a single dummy satellite monitoring station as a graph and table?
13. Does the program correctly allow you to display information from two dummy satellite monitoring stations as a graph and table?
14. Does the program correctly allow you to display information from three dummy satellite monitoring stations as a graph and table?
15. Does the program correctly allow you to display information from four dummy satellite monitoring stations as a graph and table?
16. Does the program correctly allow you to display information from five dummy satellite monitoring stations as a graph and table?
17. Does the program correctly allow you to display information from 10 dummy satellite monitoring stations as a graph and table?
18. Does the program correctly allow you to display information from 100 dummy satellite monitoring stations as a graph and table?
19. Does the program correctly display an error message if no satellite monitoring stations are found?
20. Does the program correctly allow you to send a dummy Bluetooth request for data to a dummy satellite monitoring station?
21. Does the program correctly receive dummy Bluetooth data from a dummy satellite monitoring station?
22. Does the program correctly allow you to send multiple dummy Bluetooth requests to multiple dummy satellite monitoring stations?
23. Does the program correctly allow you to receive multiple dummy Bluetooth data packets from multiple dummy satellite monitoring stations?
24. Does the program correctly allow you to display information from a single satellite monitoring station as a table?
25. Does the program correctly allow you to display information from a single program station as a graph?
26. Does the program correctly allow you to display information from a single satellite monitoring station as a graph and table?
27. Does the program correctly allow you to display information from two satellite monitoring stations as a graph and table?
28. Does the program correctly allow you to display information from three satellite monitoring stations as a graph and table?
29. Does the program correctly allow you to display information from four satellite monitoring stations as a graph and table?
30. Does the program correctly allow you to display information from five satellite monitoring stations as a graph and table?

31. Does the program correctly allow you to send a Bluetooth request for data to a satellite monitoring station?
32. Does the program correctly receive Bluetooth data from a satellite monitoring station?
33. Does the program correctly allow you to send multiple Bluetooth requests to multiple satellite monitoring stations?
34. Does the program correctly allow you to receive multiple Bluetooth data packets from multiple satellite monitoring stations?
35. Does the program correctly display an error message if a satellite monitoring station goes offline during a transmission?
36. Does the program correctly display a message letting you know it is has sent a request to a satellite monitoring station and is now waiting for a reply?
37. Does the program correctly display a message letting you know that it is receiving data from a satellite monitoring station?
38. Does the program correctly display a message letting you know that the program has finished communications with all of the satellite monitoring stations?
39. Does the program correctly display a message letting you know that a satellite monitoring station has gone offline?
40. Does the program correctly display a message letting you know that a new satellite monitoring station has been detected in the network?

Table 71.1: Central Hub Test Results

Test	Result	Tester	Notes
Test M1			
Test M2			
Test M3			
Test M4			
Test M5			
Test M6			
Test M7			
Test M8			
Test M9			
Test M10			
Test M11			
Test M12			
Test M13			
Test M14			
Test M15			
Test M16			
Test M17			
Test M18			
Test M19			
Test M20			
Test M21			
Test M22			

Table 71.2: Central Hub Test Results

Test	Result	Tester	Notes
Test M23			
Test M24			
Test M25			
Test M26			
Test M27			
Test M28			
Test M29			
Test M30			
Test M31			
Test M32			
Test M33			
Test M34			
Test M35			
Test M36			
Test M37			
Test M38			
Test M39			
Test M40			

10.6 Application Software Test Environment

For our Android application testing we plan to do as many tests as we can think of to ensure that we find and fix as many bug as possible that may exist in the program as we don't wish to release an application that has bugs in it. We will first try to find and fix all critical errors which cause the application to crash. We will then work on less critical bug finding and fixing to ensure that everything works the way it should. Once that is all done we will finally focus on the bugs that we feel are not as crucial to fix such as cosmetic bugs or bugs that don't interfere with functionality or stability.

We will test the application on a desktop and laptop to search for and fix any coding or logic errors we can find. Once we are satisfied with how it is working on the Android application emulator we will transfer it to the Android devices we have available to us. This will allow us to further test for crash and logic errors we may have missed as well as address any interface or cosmetic errors we can find. Once we have the application working correctly and to our satisfaction on both the desktop and laptop emulators as well as the Android devices we have available to us will we be able to call the application done for now.

We will then be able to focus on adding any addition features or enhancements we desire to the application. Any addition features or enhancements we add to the application or remove from the application. This will then reset our application testing requiring us to do additional testing on the modified code to verify that it is stable. Then we will have to redo our integration testing on all parts of the application that the new code interacts with.

We will have to test our application again on both the emulators and devices to ensure that we find any and all errors that we can for runtime, functional, logic, and cosmetic.

We plan to have testing on the Android devices done by us the developers as well as by potential users to help us find and errors we may have overlooked or no thought to test. We plan to only have developers test the code on the Android device emulator since the code there will not be able to interact with the same way it can on an actual Android device.

10.7 Application Software Specific Testing

For our Android application testing we will do the following tests to help us verify that our application works correctly and as expected in as many situations as possible. We plan to test each section of the code by itself before we do integration testing where feasible. We will then where feasible integrate the code one section at a time.
We plan to fully test each section of code before we go back and attempt to fix any errors in it unless the error we find is a critical error. This will allow us to spend less time testing overall we feel. We will after each critical error or if no critical errors are found after each section has been tested go back and fix any errors that where found and repeat this till we don't find any errors. After and only after we have deemed a section error free will we move onto integration testing with those sections. At this time we will fully test the new combined section again. We plan to repeat this process till we have fully integrated all of the sections into a final full program.

Next we will test the program as a whole first by ourselves and then we will have others test the program who are outside of our group so that we can have some fresh minds and eyes testing our program not fully knowing how we designed it so as to find an unbiased source that can test our program for errors which we may have but have been blind to.

Test A1 – Test A5: Android application function & integration testing

1. Does the Date and Time class correctly compile?
2. Does the Draw class correctly compile?
3. Does the Draw class correctly compile?
4. Does the Database class correctly compile?
5. Does the entire application compile without errors?

Test A6 – Test A22: Android application emulator function testing

6. Does the application once compiled and running correctly display the date and time?
7. Does the application correctly allow you to rename a satellite monitoring station?
8. Does the application correctly allow you to add a new satellite monitoring station?
9. Does the application correctly allow you to remove an existing satellite monitoring station?
10. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a table?
11. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a graph?

12. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a graph and table?
13. Does the application correctly allow you to display information from two dummy satellite monitoring stations as a graph and table?
14. Does the application correctly allow you to display information from three dummy satellite monitoring stations as a graph and table?
15. Does the application correctly allow you to display information from four dummy satellite monitoring stations as a graph and table?
16. Does the application correctly allow you to display information from five dummy satellite monitoring stations as a graph and table?
17. Does the application correctly allow you to display information from 10 dummy satellite monitoring stations as a graph and table?
18. Does the application correctly allow you to display information from 100 dummy satellite monitoring stations as a graph and table?
19. Does the application correctly allow you to send a dummy Bluetooth request for data to a dummy central hub?
20. Does the application correctly receive dummy Bluetooth data from a dummy central hub?
21. Does the application correctly allow you to send multiple dummy Bluetooth requests to a dummy central hub?
22. Does the application correctly allow you to receive multiple dummy Bluetooth data packets from a dummy central hub?

Test A23 – Test A50: Android device testing

23. Does the application install?
24. Does the application correctly uninstall?
25. Does the application open once installed?
26. Does the application close when you close it?
27. Does the application once installed and running correctly display the date and time?
28. Does the application correctly allow you to rename a satellite monitoring station?
29. Does the application correctly allow you to add a new satellite monitoring station?
30. Does the application correctly allow you to remove an existing satellite monitoring station?
31. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a table?
32. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a graph?
33. Does the application correctly allow you to display information from a single dummy satellite monitoring station as a graph and table?
34. Does the application correctly allow you to display information from two dummy satellite monitoring stations as a graph and table?
35. Does the application correctly allow you to display information from three dummy satellite monitoring stations as a graph and table?
36. Does the application correctly allow you to display information from four dummy satellite monitoring stations as a graph and table?

37. Does the application correctly allow you to display information from five dummy satellite monitoring stations as a graph and table?
38. Does the application correctly allow you to display information from 10 dummy satellite monitoring stations as a graph and table?
39. Does the application correctly allow you to display information from 100 dummy satellite monitoring stations as a graph and table?
40. Does the application correctly display an error message if no central hub is found?
41. Does the application correctly allow you to send a Bluetooth request for data to the central hub?
42. Does the application correctly receive Bluetooth data from the central hub?
43. Does the application correctly allow you to send multiple Bluetooth requests to the central hub?
44. Does the application correctly allow you to receive multiple Bluetooth data packets from the central hub?
45. Does the application correctly display an error message if the central hub goes offline during a transmission?
46. Does the application correctly display a message letting you know it is has sent a request to the central hub and is now waiting for a reply?
47. Does the application correctly display a message letting you know that it is receiving data from the central hub?
48. Does the application correctly display a message letting you know that the application has finished communications with the central hub?
49. Does the application correctly display a message letting you know that the central hub has received a report that a satellite monitoring station has gone offline?
50. Does the application correctly display a message letting you know that the central hub as detected a new satellite monitoring station in the network?

Table 72.1: Android Application Test Results

Test	Result	Tester	Notes
Test A1			
Test A2			
Test A3			
Test A4			
Test A5			
Test A6			
Test A7			
Test A8			
Test A9			
Test A10			
Test A11			
Test A12			
Test A13			
Test A14			
Test A15			
Test A16			
Test A17			

Table 72.2: Android Application Test Results

Test	Result	Tester	Notes
Test A18			
Test A19			
Test A20			
Test A21			
Test A22			
Test A23			
Test A24			
Test A25			
Test A26			
Test A27			
Test A28			
Test A29			
Test A30			
Test A31			
Test A32			
Test A33			
Test A34			
Test A35			
Test A36			
Test A37			
Test A38			
Test A39			
Test A40			
Test A41			
Test A42			
Test A43			
Test A44			
Test A45			
Test A46			
Test A47			
Test A48			
Test A49			
Test A50			

11.0 Administrative Content

We broke the work load down such that we had a main and a secondary person on each task of the same discipline. This way we kept both computer engineering majors and electrical engineering majors working together on related tasks as we have listed below. This however was only to be used as a guild as who to check in with about the status of a given component. We all intend to work on most or all of the parts however. This will allow us all to better focus our core engineering components as well as further expand our knowledge into similar and related engineering components.

Table 73: Group Member Responsibilities

Main Component	**Subcomponents**	**Persons Responsible**
Central Hub		
	LCD display	Zaida Gonzalez then Wayne Rodenburg
	Bluetooth Device	Zaida Gonzalez then Wayne Rodenburg
	Microcontroller	Wayne Rodenburg then everyone
	Circuit Board	Alejandro Dirksen then Marisa Vega
Individual Satellite Monitoring Stations	(Five in all)	
	Bluetooth Devices	Zaida Gonzalez then Wayne Rodenburg
	CT Current Meters	Alejandro Dirksen then Marisa Vega
	Surge Protectors	Marisa Vega then Alejandro Dirksen
	Relays	Alejandro Dirksen then Marisa Vega
	Outlets	Marisa Vega then Alejandro Dirksen
	Microcontrollers	Alejandro Dirksen then everyone
	Circuit Boards	Marisa Vega then Alejandro Dirksen
Android Application		
	Android Application	Wayne Rodenburg then Zaida Gonzalez

11.1 Milestone Discussion

We have a tentative timeline with milestones listed below. We have estimated based on other projects, past experiences, and guesses as to how long it will take to come up with the times needed for each milestone listed. We have had to adjust some of them to take either more or less time however. Many of the start dates we had hoped to hit have

Table 74: Project Milestones

Milestone	Expected Time to Complete Each Milestone	Expected Start Dates & Expected Completion Dates
Form Group and Pick Project	1 weeks	August 19th – September 9th
Research	4 months	September 2nd – February 1st
Decide on Project Features	1 month	September 2nd – October 1st
Form a Design we all agree on	1 month	September 2nd – October 1st
Decide on parts we will use	3 months	September 9th – December 1st
Duke Energy Grant Proposal		Submit by October 18th
Order the Parts	3 months	October 1st – January 1st
Meter Design	1 months	October 1st – December 1st
Plug Design	1 months	October 1st – December 1st
Relay Design	1 months	October 1st – December 1st
Surge Protector Design	1 months	October 1st – December 1st
Android Application	5 months	October 1st – March 1st
Android Testing	6 months	October 1st – April 1st
Bluetooth Integration	4 months	October 1st – February 1st
Circuit Board Design	2 months	November 1st – February 1st
Circuit Board Testing	3 months	November 1st – March 1st
Microcontroller Coding	3 months	November 1st – March 1st
Microcontroller Testing	3 months	November 1st – March 1st
Interface Testing	5 months	November 1st – May 1st
Senior Design 1 Paper Due		December 2nd 2013
First Prototype	1 months	December 1st – February 1st
First Prototype Testing	2 months	December 1st – March 1st
Second Prototype	1 months	January 1st – March 1st
Second Prototype Testing	2 months	January 1st – April 1st
Third Prototype	1 months	February 1st – April 1st
Third Prototype Testing	2 months	February 1st – May 1st
Senior Design Day Showcase		April 18th 2014
Final Presentation		April 14th – 17th 2014

11.2 Budget and Finance Discussion

To come up with a projected budget for our project we did research as well as used past projects some similar and some not to give us a better guild for our budget. This way we could see if there were any budget concerns we had not realized and budgeted for as well as get an idea of the price range of the various parts we plan to use. This would also give us some guidance on parts we may wish to use or steer clear of given past groups experiences with them both good and bad.

Table 75: Projected Project Budget

Item	Expected Cost
LCD 1x	$ 150
Bluetooth Devices 6x	$ 400
Outlets 5x	$ 10
Surge Protectors 5x	$ 50
Relays 5x	$ 25
Meters 5x	$ 25
Microcontroller for the Hub with memory card 1x	$ 50
Microcontrollers for the Stations 5x	$ 150
Wiring	$ 15
Housing for the Hub 1x	$ 10
Housing for the Stations 5x	$ 50
Hard Drive	$ 100
Circuit Boards 6x	$ 150
Shipping and Handling	$ 200
Board assembly and learning how to solder	$ 150
Printing and Binding for Senior Design I	$ 20
Printing, Binding, Display for Senior Design II	$ 50
Total Estimated amount	$ 1605

11.3 Duke Energy Grant Proposal

Below is a copy of our accepted Duke Energy grant proposal.

Background
There is an energy crisis in the world, not only in the transportation section but also in generating, distributing, and consuming electricity. Adding more gadgets and devices that are power hungry into our everyday life increases the energy consumption even more. The field of power efficiency is not progressing at the same rate that we consume power. This is why there are many researchers investigating and working on getting more energy from different resources as well as ways to save the energy we currently have available.

Objective
Our idea for the project focuses on making consumers of electricity aware of the consumption of energy and how some gadgets and devices are eating energy inadvertently, mainly focusing on something called phantom energy, or better explained, when an electronic is not completely off.

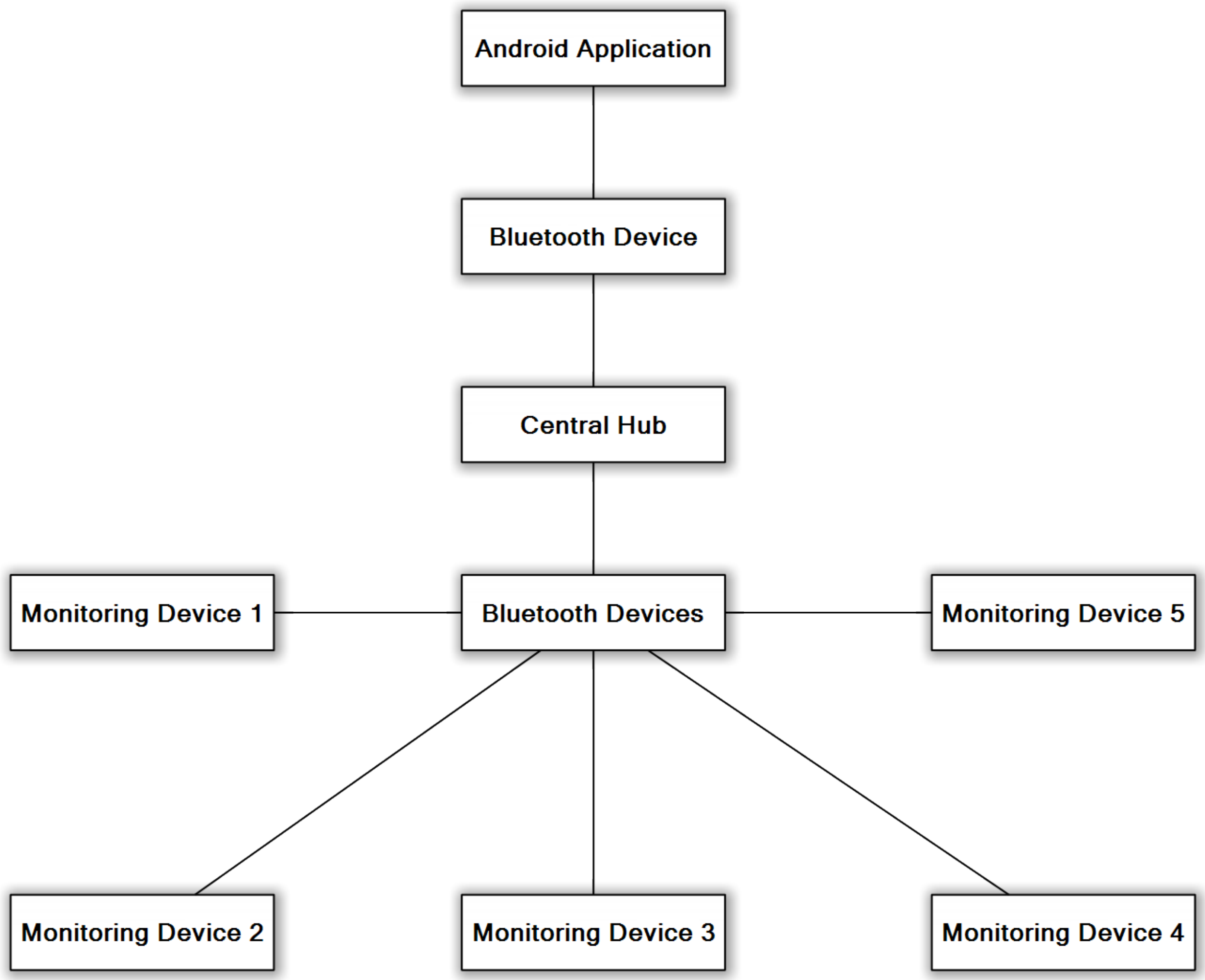
Goal

A small low power device that is able to monitor and track your power usage (in dollars amount). We should have several monitoring devices (the same power device) and a single central hub that they all communicate with. We plan to have a LCD display to display this information to the user on (what information). We plan to incorporate a breaker inside of each monitoring device to cut off power to a device (either by power surge, non-use of the device to avoid phantom energy, or by wireless control from the phone of the user). This way the device can truly be off and no longer using any power. We anticipate this will be most helpful for computers, monitors, televisions, Blu-ray players, as well as smaller appliances and devices. We plan to gather and store (the data obtain from these devices, including power consumption, peaks in voltages for future reference for a period of 10 years) the data of usage for the devices plugged into the monitoring devices. Then we plan to transmit this information to the central hub every hour or when the central hub requests it to be sent if the user wants to know sooner (This with the purpose on mind to keep track of spending habits of electricity, if it is making the bill much higher than usual and/or the devices is using too much phantom energy). We then plan to store, and allow the user to view this information as they see fit to help them lower their power consumption.

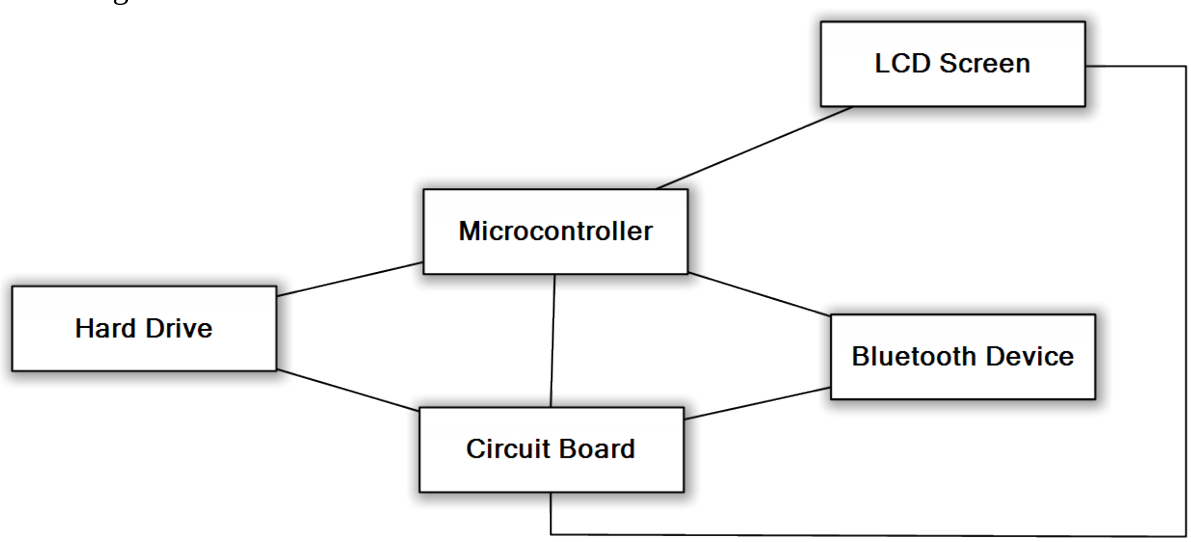
Proposal

We are looking to create an affordable and feasible way to allow everyone to reduce their energy consumption and their power bill. We plan to create a robust and reliable mesh network with the Bluetooth controlled devices that will allow the consumer to completely turn off items they are not using such as stoves, ovens, microwaves, dishwashers, washing machines, driers, DVD and Blue Ray players, TVs and any other items that are hooked up to the system not just off but completely off by disconnecting them from the power so as to keep them from drawing phantom energy when they are not in use. Some of these devices such as hot water heaters and pool pumps are already part of your EnergyWise Home program. These items can also be monitored and controlled with our system as well. This could allow for an option to have the consumer add some or all of these other items that are normally not on the EnergyWise Home program to it when they are not home, but even more importantly it could allow for them to be disconnected from the power grid completely. This would not only save them cash on their bill, but also Duke Energy as you wouldn't need to produce the energy nor the harmful CO_2 emissions to power them when they are not in use by anyone.

This is a general overview of our project.



This is a general overview of the central hub.



This is a general overview of the monitoring devices.

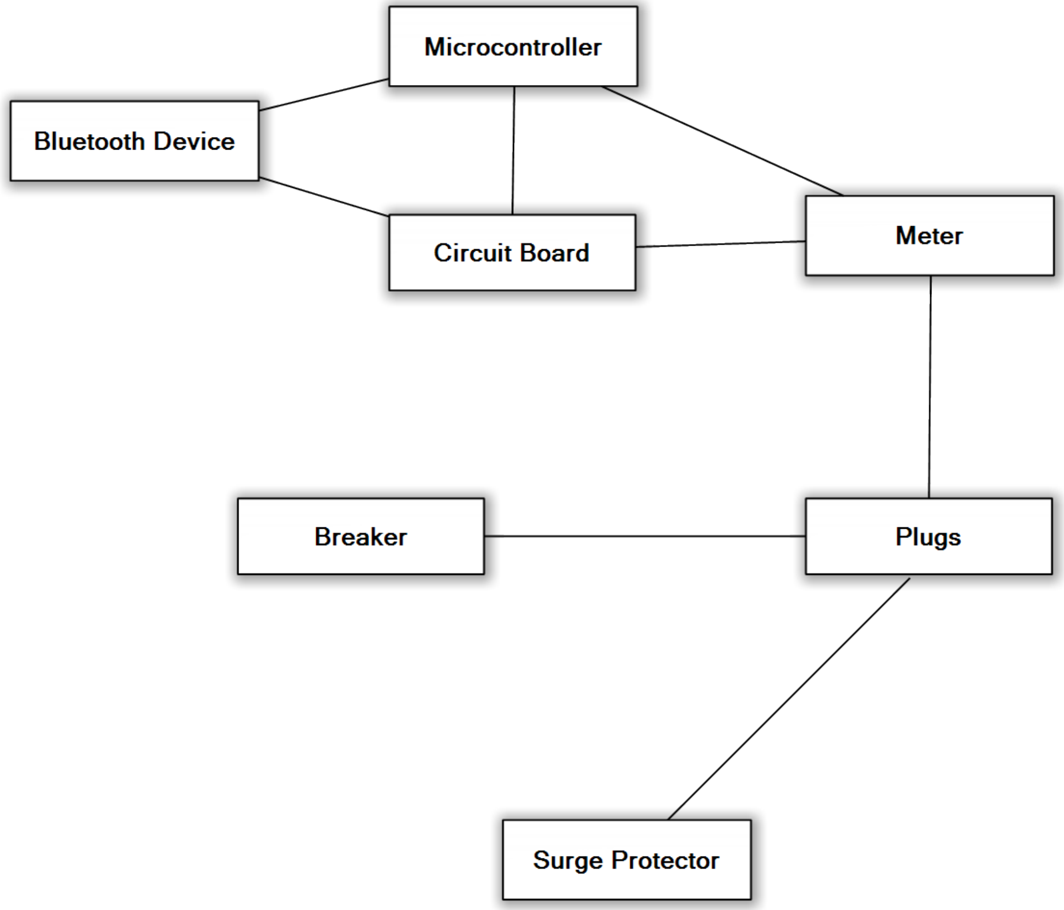


Table 76: Our Projected Funding is as Shown Below:

LCD 1x	$ 150
Bluetooth Devices 6x	$ 400
Outlet 5x	$ 10
Surge Protectors 5x	$ 50
Breakers 5x	$ 25
Meter 5x	$ 25
Microcontroller for the Hub with memory card 1x	$ 50
Microcontrollers for the Stations 5x	$ 150
Wiring	$ 15
Housing for the Hub 1x	$ 10
Housing for the Stations 5x	$ 50
Hard Drive	$ 100
Circuit Board 6x	$ 150
Shipping and Handling	$ 200
Board assembly and learning how to solder	$ 150
Total Estimated amount	$ 1535

Appendices

Appendix A – Sponsors and Acknowledgments

We would like to thank Duke Energy for their sponsorship of our project.
We would like to thank Texas Instruments for their sponsorships though the Texas Instruments Innovation Challenge.

Appendix B – Table of Figures

Appendix C – List of Tables

Appendix D – Footnotes and References for Tables and Figures

References:

[i] Table 1: Information taken from
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[ii] Table 2:
???

[iii] Table 3:
???

[iv] Table 4:
???

[v] Table 5:
???

[vi] Table 10:
???

[vii] Table 11:
???

[viii] Table 13: Information taken from
The ZETER semiconductors current measurement application handbook.

[ix] Table 12: Information taken from
https://www.sparkfun.com/products/11925
https://www.sparkfun.com/products/11677

[x] Table 3: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xi] Table 4: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xii] Table 2: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xiii] Table 5: Information taken from

http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xiv] Table 6: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xv] Table 8: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xvi] Table 7: Information taken from
http://www.4dsystems.com.au/downloads/microLCD/uLCD-32PTU/Docs/uLCD-32PTU-Datasheet-REV1.5.pdf

[xvii] Table 9: Information taken from
https://www.sparkfun.com/products/11786
https://www.sparkfun.com/products/10823

[xviii] Figure 1: Image taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf
(No permission required from sparkfun.com)

[xix] Table 10: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xx] Table 11: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxi] Table 12: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxii] Table 13: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxiii] Table 15: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxiv] Table 14: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxv] Table 16: Information taken from
https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf

[xxvi] Figure 2: Image taken from

https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf
(No permission required from sparkfun.com)

[xxvii] Table 18: Information taken from
http://www.matrixmultimedia.com/resources/files/datasheets/RF%20Solutions%20Transciever.pdf

[xxviii] Table 19: Information taken from
http://www.matrixmultimedia.com/resources/files/datasheets/RF%20Solutions%20Transciever.pdf

[xxix] Table 17: Information taken from
http://www.matrixmultimedia.com/resources/files/datasheets/RF%20Solutions%20Transciever.pdf

[xxx] Table 20: Information taken from
https://www.sparkfun.com/products/10416
https://www.sparkfun.com/products/10417
https://www.sparkfun.com/products/10421
https://www.sparkfun.com/products/10414
https://www.sparkfun.com/products/10418
https://www.sparkfun.com/products/10420

[xxxi] Development cost taken from
https://developer.apple.com/programs/ios/

[xxxii] Table 21: taken from
http://developer.android.com/about/dashboards/index.html

Understanding AC source Specification and terminology. California Instruments. Retrieved from:
http://www.programmablepower.com/Application_Notes/app_downloads/App105_AC-Source_Specifications_&_Terms.pdf

MSP430 LaunchPad Design and Evaluation Kits & BoosterPack Plug-in Modules. Retrieved from:
http://www.ti.com/lsds/ti/microcontroller/16bit_msp430/tools_software.page#msp430pad

Electromechanical Relays Technical Information. Omron Electronics. Retrieve from:http://www.components.omron.com/components/web/PDFLIB.nsf/0/725A59B5DC914C3A85257201007DD5C4/$file/Relay_Tech_Information_0911.pdf

Current Shunt Monitors.(2013). Texas Instruments. Retrieved from:
http://www.ti.com/lit/ml/slyb194/slyb194.pdf

Products for MSP430 Ultra-Low Power 16-bit MCUs. Texas Instruments. Retrieved from:
http://www.ti.com/lsds/ti/microcontroller/16-bit_msp430/products.page

Application Guide RF & Protection Devices. Infineon. Retrieved from:
http://www.infineon.com/dgdl/Infineon_RPD_AppGuide_Protection.pdf?folderId=db3a304314 41fb5d01146ec76de80910&fileId=db3a3043341f67a1013446a4a06601b2

Engineer It-How to test power supplies-Overview. Texas Instruments. Retrieved from:
www.ti.com/testingpoweroverview

DI-57 Design Idea. PA-Switch, 60W DC-DC converter. Power Integration. Retrieved from:
http://www.powerint.com/sites/default/files/PDFFiles/di57.pdf

AN39 Current measurement application handbook. Zeter semiconductors. Retrieve from:
http://application-notes.digchip.com/040/40-33407.pdf

Power Supply: AC/DC, isolated, w/PFC,>90W.Texas Instruments. Retrieved from:
http://www.ti.com/solution/power_supply_ac_dc_isolated_w_pfc_greaterthan_90w

[xxxiii] ***Taken from TI website Current Shunt Monitor common-mode range***

[xxxiv] ***Taken from TI website Current Shunt Monitor common-mode range***