IoT Environmental Monitoring

PROJECT PLAN

Team 45

Advisor/Client: Dr. Geiger

Team Members/Roles

Tyler Fritz - Software Developer - Web Server and Home Node

Ahmed Abuhjar - Hardware Developer - Leaf Node and Home Node

Dong Xing - Hardware Developer -HomeNode&LeafNode Role

Haoyue Ma - Hardware Developer - Leaf Node and Home Node

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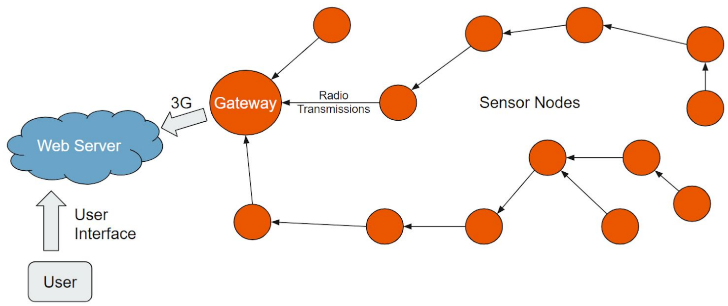


Figure 1 *Conceptual sketch of mesh network.*

Figure 2 *Watermark soil moisture sensors*

Figure 3 *Calibration test Experiment*

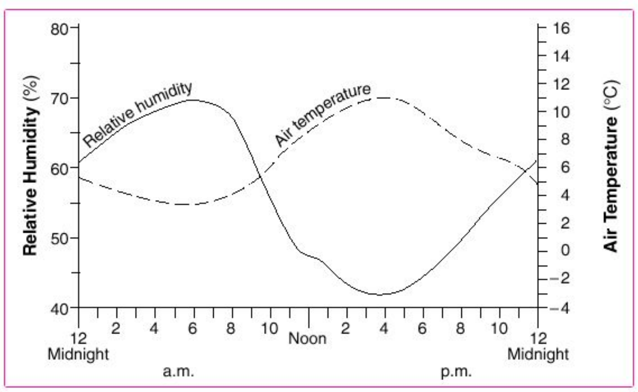


Figure: the relation between air's temperture and relative humidity

Figure 6 *The relation between air temperature and relative humidity*

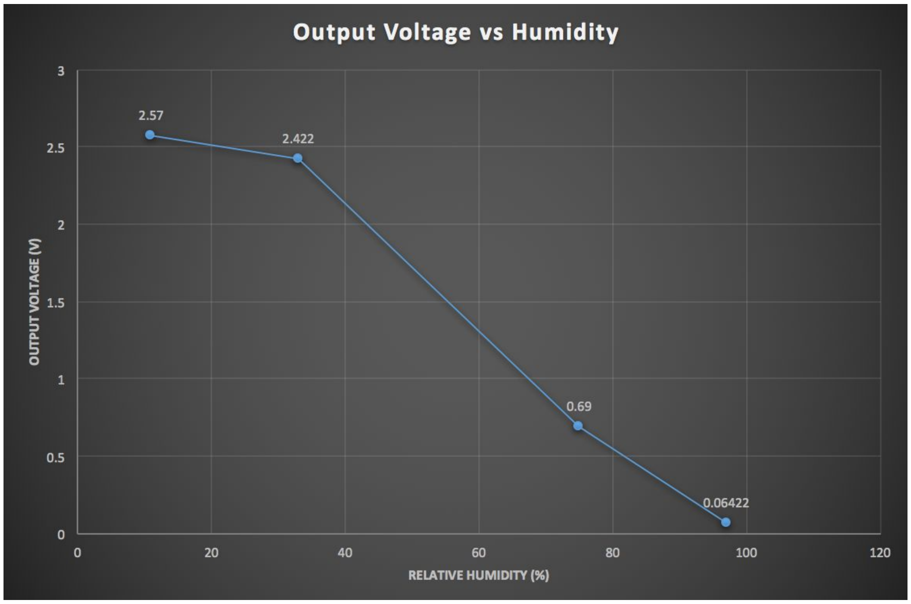
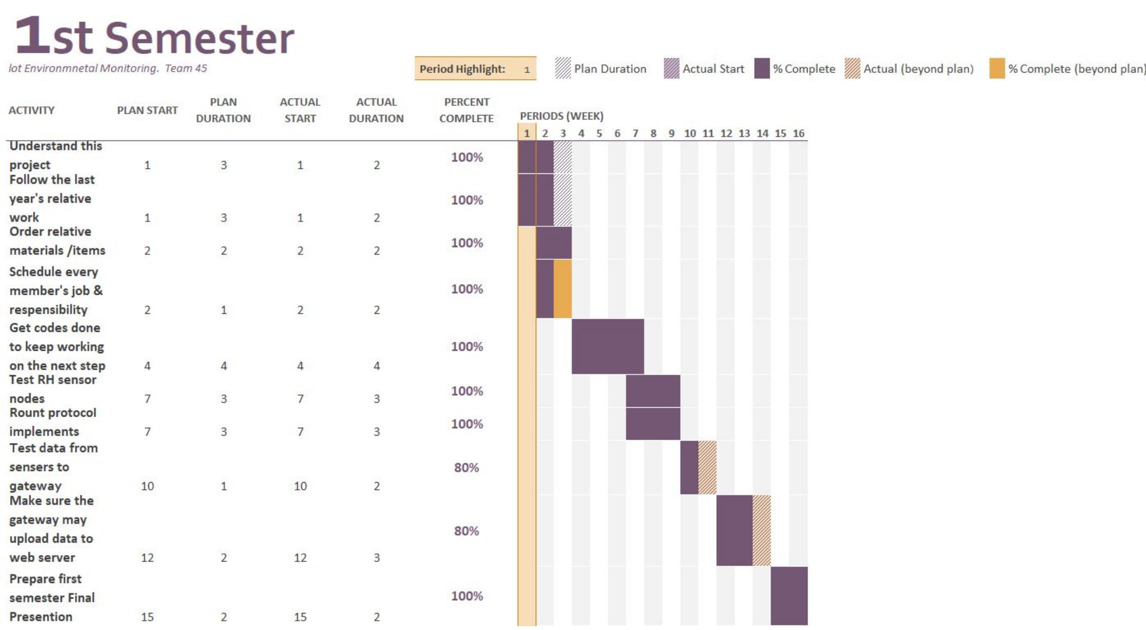


Figure 7 *Calibration Test Results*



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Understand this project	1	3	1	2	100%
Follow the last year's relative work	1	3	1	2	100%
Order relative materials /items	2	2	2	2	100%
Schedule every member's job & respensibility	2	1	2	2	100%
Get codes done to keep working on the next step	4	4	4	4	100%
Test RH sensor nodes	7	3	7	3	100%
Rount protocol implements	7	3	7	3	100%
Test data from sensers to gateway	10	1	10	2	80%
Make sure the gateway may upload data to web server	12	2	12	3	80%
Prepare first semester Final Presention	15	2	15	2	100%

Figure 8 *Project Timeline*

2nd Semester

Iot Environmnetal Monitoring. Team 45

Period Highlight: 1 | Plan Duration | Actual Start | % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Run web server	1	2	0	0	0%
Investigate PCB for the leaf	1	4	0	0	0%
Node PCB order	1	2	0	0	0%
Plan case design	1	3	0	0	0%
Build sensor node with PCB	3	4	0	0	0%
System Intergation	7	2	0	0	0%
Project testing	9	2	0	0	0%
Get improvement	11	2	0	0	0%
User acceptance testing	13	2	0	0	0%
Prepare Final Presention	15	2	0	0	0%

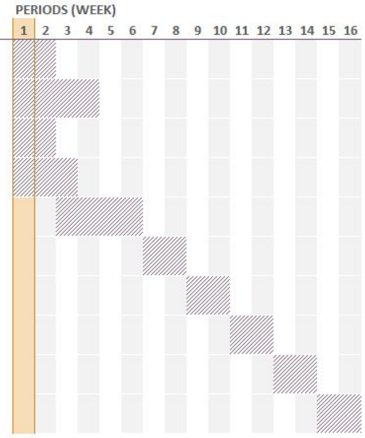


Figure 9 *Project Timeline for second semester*

Item	Cost Per Unit	Required Count	Total Cost
Gateway	$108.00*	1	$108
Sensor Node	$13.94	~50	$697
Web Server	$30.53**	1	$30.53

Total Cost of Solution = **$835.53**

Figure 10 *Estimate cost of the project*

List of Symbols

Radio transceiver unit by which the signals between the nodes can be transmitted and received.

User Interface (i.e. computer, LCD, web-server.. etc)

List of Definitions

Gateway Node / Home Node, which is the final node to receive all data from leaf nodes and then upload these data to the web-server.

Leaf Node / **Sensor Node**. Data will be tested and collected by sensors on each leaf node, and then the collected data will be transferred in-between leaf nodes and finally to the home node.

1. Introductory Material

1.1 Acknowledgement

Project name: IoT Environmental Monitoring System.

Team
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- Tyler Fritz
- Dong Xing
- Haoyue Ma
- Yuanzhe Wang

Mentor: Prof. Randall L. Geiger

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1.2 Problem Statement

Problem Identification

Our project is to create an intelligent IoT environmental monitoring system that collects soil readings from in-ground sensors and analyzes the data to determine the moisture levels of the user's land. The purpose of this product is to make systems that monitor the environment easier and smarter by providing customers and farmers with an automated system solution that will collect data that is sent to a website that provides remote access to the system and is easy to use. For example, if our client is a farmer, they will then be able to determine if the crops need to be irrigated, which will not only maximize the agricultural production with minimum cost, but also will minimize the burden of farmers who could find themselves away from their farms for extended periods of time.

The current solutions on the market that provide this functionality are very expensive and provide very few points of data, which is not ideal because soil moisture data is very useful, and accurate measurements of this data would have many uses such as improving crop yields.

Purpose and Use

Our system is designed to take advantage of soil moisture sensors to provide a smart monitoring system for users. All monitoring and measuring activity will be governed by a smart controller which will be able to collect information about current soil moisture levels and allow the user to display the data on a website application.

Proposed approach to solve the problem

Our product will be a mesh network with two classes of nodes, a central control unit (gateway node), soil moisture sensors (leaf nodes), and a web application that work and communicate effectively with each other. Each soil sensor node will collect data on soil moisture. This information is sent to the gateway node (Home node), which will be 3G and 4G enabled, and can upload data to an off-site web server. Because the sensor nodes are cheap and have little battery life, they will not all have a strong enough radio to transmit messages directly to the gateway node. Therefore we need to employ a message routing protocol that allows the sensor nodes to relay messages between themselves back to the gateway node.

Our solution will succeed in being cheaper than the current solutions on the market because the components used in our system are low power and cheap. We are taking advantage of the fact that it requires much less energy to transmit messages in many short hops than one large hop. Because the current solutions transmit their data directly to its destination in one hop, the radio transmitters they use expensive and use a high amount of power.

1.3 Operating Environment

Our project's primary operating environment will be Iowa farmland during the Spring, Summer, and Fall. This will expose our components to rain, dust, mud, and wind. This will require us to create a casing for the leaf nodes that will account for these conditions. Additionally the casing must not interfere with the radio transmitter and receiver of the sensor nodes.

1.4 Intended Users and Intended Uses

IoT environmental monitoring systems have been used in different applications, such as military, agriculture, sports, and medicine. Agriculture is considered as one of the most favorable applications for this system because it has the potential to improve crop yields and minimize the burden of farmers who could find themselves away from their farms for extended periods of time.

Our system can be used to increase agricultural yield. Accordingly, various agricultural applications can utilize the system, such as for monitoring climate and using soil moisture data to forecast the health of crops and the quality of agricultural products. By observing weather conditions such as temperature, humidity, and soil moisture, IoT environmental monitoring systems can help make informed decisions about land. Other types of sensor nodes can be added to the our system to make it a system that it is useful for many different types of environmental monitoring.

1.5 Assumptions and Limitations

Assumptions

- Leaf nodes will have a density of one node per square km. If they are spread apart further than this, they may not be able to communicate with each other.
- Leaf nodes will only be used for a span of 4-6 months.
- The radio transmitter from the leaf nodes will have a range greater than 1 km. If this is not true, the network will not be able to reliably communicate information.
- There will be cellular reception where the home node is placed. It will need this to be able to upload data to the web server.
- Our web server will not be required to serve high numbers of clients at the same time. The number of clients we have will be in the range of 0 to 10,000.

Limitations

- The radio transmitter takes a sizable amount of power and it is not reasonable to expect someone to visit nodes to refresh batteries when they run out. We must be very careful with how much we use the radio transmitter.
- We have a small budget for leaf nodes. It is necessary that they are cheap because there will be many of them.
- Our solution requires casing and no one in our team has experience designing cases.

1.6 Expected End Product and Other Deliverables

Our product will consist of a home node, which will be the internet gateway of the mesh network, soil sensor nodes, also known as leaf nodes, and a web application. These components communicate with each other as shown in *Figure 1*. Our goal for the end of the year is to have at least one home node, 50 sensor nodes, and one web server functioning and tested.

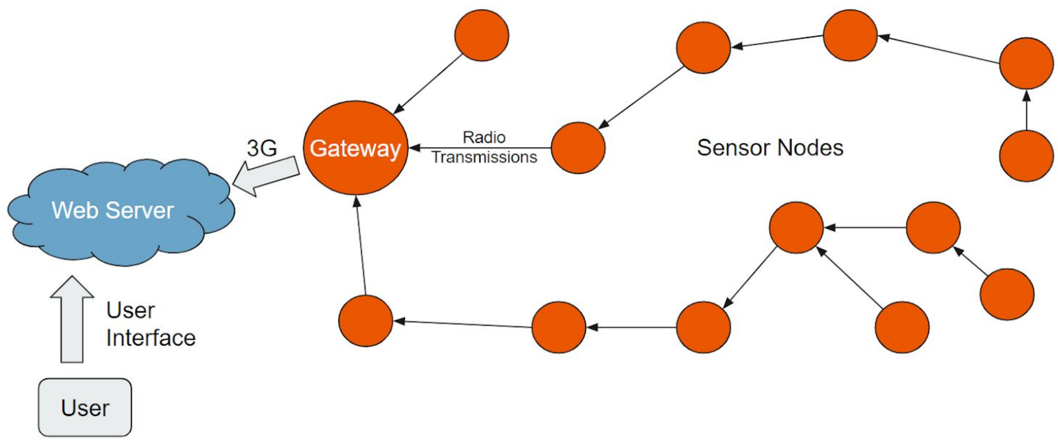


Figure 1. Conceptual sketch of mesh network

Leaf Nodes

Our leaf nodes will be comprised of an Atmega328p microcontroller, a custom PCB created for this project by a previous senior design team, multiple sensors, including the temperature and soil moisture, and a radio transceiver. They will run a program that allows them to record, transmit and relay data to the home node through other leaf nodes. We will have at least one fully functioning by *December of 2018* and 50 functioning by *May of 2019*.

Soil Moisture Sensors

To lower the cost of our system, we will be creating our own soil moisture sensors instead of buying them. These sensors will be made using Gypsum. Gypsum is very hygroscopic which makes it a good material to use for sensing moisture levels. Additionally, it is a cheap material which makes it ideal for our application. We plan on having one of these sensors completed by *December 2018* and 50 completed by *May of 2019.*

Home node

This node will be used as a means of communication between the leaf nodes and the web server. It will be a small computer that has internet access and needs to be in an area with cellular service. It will receive environmental data from the leaf nodes, then upload it to the web server through a cellular connection. This will be delivered by *December of 2018.*

Web Server

One of the features that makes our system smarter than other environmental monitoring systems is its ability to analyze soil moisture readings and store all soil readings from the microcontroller into a database by utilizing a web server. These readings are then analyzed to determine whether the crops are in a good health and whether they soil needs to be watered. The web server will have a simple user interface that consists of a login page so that only the owner of the data is allowed to see the data. This will be delivered by *April 2018.*

2. Proposed Approach and Statement of Work

2.1 Objective of the Task

Our goal is to create and test a low-cost wireless sensor network that can be used for environmental monitoring. We will monitor soil moisture levels and temperature to start but it will be easy to add any kind of sensor later on. We have a target manufacturing cost of less than $10 per leaf node and $100 per home node. The leaf nodes will transmit their data with radio transmitters to the home node which will upload it to a web application.

2.2 Functional Requirements

Requirement 1 - The leaf nodes must be able to accurately take measurements of the soil moisture levels.

Requirement 2 - The leaf nodes must be able to accurately record the soil temperature.

Requirement 3 - The leaf nodes must be able to transmit data throughout the network to the home node.

Requirement 4 - The home node must be able to upload data to the web server without a wired connection.

Requirement 5 - The home node must be able to issue commands to the leaf nodes.

Requirement 6 - The network must be able to automatically handle the death of a node.

Requirement 7 - Any node must be able to communicate with any other node.

Requirement 8 - The web server must be able to store the data long term and must not lose and data in the event of a crash.

Requirement 9- The web server must be able to serve data to clients using modern web browsers.

Requirement 10- The web server must allow users to only view their own data with login credentials.

Requirement 11- The gateway node must be able to communicate with every node.

Requirement 12- The sensor nodes must have a sleep cycle where they only wake up during certain times in the day in order to save power.

2.3 Constraints Considerations

2.3.1 Standards

Our project contains systems with standards we must adhere to. Such standards are HTTPS, for communication with web server, SQL, when querying database, and IEEE best practice standards for writing c++. Most of these standards will be fairly easy to adhere to because the tools we are using automatically use them. However, the most difficult to follow will be the coding standards for c++. To make sure that this standard is followed, we will all become proficient in the standard and perform code reviews on each other's code.

2.3.2 Ethical Considerations

If we are successful in making our leaf nodes very cheap, it is unlikely our users will go out and retrieve them after their batteries have died. If the leaf nodes are not biodegradable they will remain where they died for many centuries to come as litter. We must keep this in mind when determining the price and biodegradability of the nodes.

2.3.2 Non-Functional Requirements

Reliability - The web server must be able to handle transient overload without losing more than 5% of the data.

Availability - The web server must be running 98% of the time.

Reliability - The home nodes and leaf nodes must immediately run our programs on startup. They can't have any configuration required on startup.

Security - Our user's personal information must not be obtainable by non-authorized parties.

Security - Only administrators will be allowed to modify non-user data.

Reliability - Nodes must be able to handle transient overload without losing more than 5% of packets.

2.4 Previous Work And Literature

To get an understanding of how we should implement the routing protocol for our mesh network, we looked into the strategies employed by a company that designs components for mesh networks called Zigbee. For their routing protocol, Zigbee uses Ad Hoc On-Demand Distance Vector (AODV)[9][10]. This protocol works by having each node store paths to other nodes in the network in a routing table. If a node needs to send a message to another node, it first checks if the route to that node is in its routing table. If it exists, then that route is used. If not, the algorithm uses a flooding technique to discover the route. This algorithm is one of the most efficient ways to communicate in a mesh network that we currently know of.

While analyzing AODV, we found that we do not require some of the functions this algorithm supports. For example, this algorithm allows any node in the network to communicate with any other node. In our solution however, we only need messages to go in one direction to the gateway node. Building this simplification into our protocol make it much easier to implement because instead of keeping a routing table with many routes, we only need to store the one route to the gateway. We decided to use similar strategies to AODV for route discovery and maintenance only built in complexity for what our solution requires. The simplifications we found make our protocol easier to implement and more efficient than a full implementation of AODV in our circumstance.

The devices in figure 2 are soil moisture sensors that are commonly used by farmers to find the moisture levels in their fields. These sensors calculate soil moisture by using the relationship that electrical resistance increases as the soil moisture decreases. We learned from this sensor that we can use the same properties it relies on to construct our own soil moisture sensor out of gypsum.

Figure 2. *Watermark soil moisture sensors*

At a price of around $50, the watermark sensor is affordable for many industries to use, but using it in our solution would be very expensive. Because water is an electrical conductor, the resistance between the wires is inversely proportional to the soil moisture (José O. Payero, et al.) [6]. We will use this property to create our own gypsum-based sensor instead of the Watermark sensor. We estimate that it will cost around about $1 to manufacture these sensors. This 98% reduction in price compared to buying Watermark sensors significantly lowers the cumulative price of the solution.

2.5 Proposed Design

Overview

A high level diagram of our solution can be seen by looking back at *Figure 1* from page 10, shown again below. There are three main components in our solution which are the sensor nodes, the gateway node, and the web server. The sensor nodes will be recording environmental data which is then relayed through other sensor nodes back to the gateway, where the data is sent to its final destination, the web server. Clients will be able to see their data by accessing the web server through an intuitive UI.

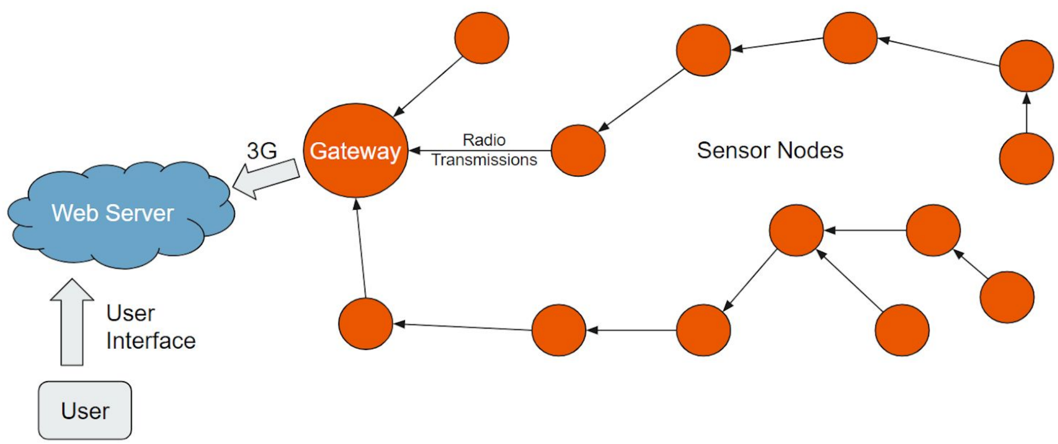


Figure 1. Conceptual sketch of mesh network

Web Server

The web server is written in a PHP framework called laravel. The backend is a Spring based API and a MySQL database. This application was written by the previous senior design group and will require some, but not an extensive amount, of additional work. The API is called using HTTPS requests, which is how the home node will be able to upload data.

One design alternative that we considered was creating a desktop application instead of using a web service. The data recorded by the mesh network would be stored in a local database and would be viewed by physically accessing the home node. We decided that this was a poor solution because the clients would not be able to access the data from anywhere and also increased the chance that the data would be lost in a disaster.

Leaf Nodes

The leaf nodes are comprised of a microcontroller, two sensors, a radio transmitter, and a pcb. The pcb was custom made for our application by a previous senior design group. The leaf nodes will record analog data with their sensors, put the data into a packet and transmit the packet to the home node by relaying it through the mesh network. The protocol used to route packets through the network will be one that is designed specifically for our application. Our protocol finds the shortest path for each node to get back to the gateway, and has each node use that path. These paths are discovered using an algorithm similar to Dijkstra's Shortest Path algorithm. Each node initially sets its distance to the gateway to infinity, and then periodically asks its neighbors what their distance to the gateway is. If a neighbor has a distance that is less than the current node's distance, the current node decides to send its messages to that node and updates its stored distance to be the neighbor's distance + 1. Then, when the node wants to send a message to the gateway, it simply needs to send its packet to that neighbor.

We need to be careful about how many times each node asks neighbors for their distance to the gateway because making these broadcasts uses some of the battery's energy. To account for this issue, each node only broadcasts these messages at the beginning of each wake cycle, or every ten seconds while the node does not know how to get to the gateway. This strategy strikes a balance between making the power usage of the network lower after it has finished setting up, while new paths are unlikely to be discovered, and ensuring that the network establishes itself quickly.

Each sensor node in our system will be powered solely by batteries, which poses a challenge because the nodes will have a limited amount of power they can use. Our approach to reduce power consumption will be through several techniques including having the nodes sleep when not in use, using an efficient routing protocol, and adjusting the range at which their radios communicate.

The sensor nodes will only wake to collect and transmit data within certain periods of time. When asleep, the power consumption of each node is reduced almost to zero. We plan for the nodes to only be awake for around five minutes per day, which means that this strategy saves around 99.6% of the power that keeping them always on would use.

To wake up at the same time, nodes will use an external crystal as their timer because the internal clock of the microcontroller we are using has an accuracy of only 90%. We still have an error issue with the crystal however because the crystal we plan to buy has an error of 20 parts per million. This means that over the course of a month each microcontroller would become out of sync by a minute. This would be a problem because the sensor nodes would not wake at the same time and the network would be able to transmit data. To get the leaf nodes back in sync, we will have the gateway broadcast a signal that when received, each sensor node will reset its clock. This event will occur daily ensuring that the sensor nodes will always be in sync in the order of a few seconds.

Depending on application, the number of sensor nodes or leaf nodes will differ from one system to another. The range between the sensors will pose a challenge as the radio signal will consume more power when transmitting data longer ranges. However, the longer the distance between the nodes the less number of sensors will be utilized in our system; hence reducing the cost of the system. A trade off is involved in deciding whether we will place the sensor nodes further apart or closer to each other. Once we verify that the system is functioning properly in receiving and transmitting data by the end of this semester, we will run several tests during the next semester to determine what range would be the best to utilize for the system.

Home Node

The home node has two primary functions, sending data it receives from the mesh network to the web server, and syncing the clocks of the leaf nodes. To make it so that the home node is able to send data to the web server it will have a cellular data connection which will allow it to send HTTPS requests. The web server will have an API which is what the home node will use to upload data. To enable the home node to be able to sync the clocks, it will have a radio that is powerful enough to contact every leaf node.

The home node will require a radio with the same range as the sensor nodes in addition to its longer range radio. This is due to the fact that during the route discovery phase, the home node must respond that it is distance 0 from the home node and only nearby nodes must be able to hear this message. In addition to that, data packets are not passively received by nodes. Before a sending nodes marks a packet as received, it must receive a confirmation that the receiving node got it. So the home node needs to be able to send these confirmation messages to any nodes that want to communicate with it.

2.6 Technology Considerations

It's very important for us to use technologies that are cheap and will be available in the long term for this project. After deliberation and research we decided to use Arduinos because they are relatively inexpensive and easy to use. In addition, we are able to buy just the Arduino's micro-controller for very little money and install it into our custom PCB for the leaf nodes. This allows us to make use of the nice features of Arduino in a cheap and scalable manner.

Using a custom PCB for our leaf nodes helps to significantly reduce their cost. It cuts out the middleman and gives us greater control over the components that are included. The previous senior design group has already designed this pcb making it an obvious component to include. In production it will cost around $0.1 to purchase this PCB.

An alternate approach to giving the sensor nodes short range radios was to give each sensor node direct access to the internet through cellular networks. Doing this would remove our need for an internet gateway node which would save around $120 per solution. This strategy would also decrease the complexity of the system because it would remove the need to create a protocol for the mesh network. Finally, this alternative would be more reliable when sensor nodes stop functioning because each node doesn't rely on other nodes to deliver messages. However, the main drawback of this solution is that it would be very expensive to get a high density of nodes over the land being monitored. Each module that connects to cellular networks costs $70, which is far more expensive than our desired price of $10 per node.

2.7 Safety Considerations

Our responsibility to make a safe design is very important. The minimization of possible risk and injury to our customer is a top priority. Due to the nature of our project dealing with electricity, we highly value safety requirements. Electronic components including the soil moisture sensors must be properly insulated against external environmental conditions. This is to ensure that they do not malfunction while in use. Also, there will be some components that will be powered directly from the grid. This includes the web server and the home node. The source will be 120v and improper wiring could leave the user exposed to currents in the range of 15-20 amps. It is crucial that these components are wired properly to ensure that no harm to the device or the costumer occurs.

2.8 Task Approach

Project tasks were assigned for each month to track the progress for the project plan.

Semester 1

	September	Oct	Nov	Dec
Nodes	**Nodes are functioning fully as they were by the end of last semester. We are fully up to speed with where the project left off**	**Has final radio with range. If new algorithm is needed, it is implemented. Data transmission from nodes has good reliability.**	**System if fully developed and is able to function as expected. Communication between components is reliable.**	**Testing and bug fixing**
Homenode	**Is capable of both sending data to the web server and receiving data from the nodes**	**New routing protocol is implemented and reliable for system.**	**System if fully developed and is able to function as expected. Communication between components is reliable.**	**Testing and bug fixing**
Web Server	**Is up and running and able to communicate with home node.**	**If additional development is required on the website, it is mostly complete.**	**Communication between components is reliable.**	**Testing and bug fixing**

Semester 2

	January	February	March	April
Sensors	Exploring and implementing new types of data sensors.	All sensors are equipped with the final sensors and hardware that would be used in production.		Finalize the documentation, do bug fixes, make the code more extendable ect.
Web Server	Editing format of web server to display additional sensor data	Additional development to make UI more user friendly. Also make more API endpoints if needed	System if fully developed and is able to function as expected. Communication between components is reliable.	Finalize the documentation, do bug fixes, make the code more extendable ect...
Casing	Construct casing in CAD. May enlist the help of an ME.	Build an initial prototype of the casing.	Stress test the casing in the real environment. Make more cases for more node prototypes	Finalize the documentation, do bug fixes, make the code more extendable ect...

2.9 Possible Risks And Risk Management

Reliability in designing the project components is vital. If the radio signal transmitted and received between the nodes interferes with unpredicted objects, that might cause issues in the data received.

When we start our large-scale test in March, the ground of the fields could be frozen making it so that we cannot record soil moisture data. This would delay the start of our tests and possibly make it so that our system is not fully tested by the end of the school year. Our mitigation strategy will be to improve our testing efficiency if this occurs and to hope that it does not.

2.10 Project Proposed Milestones and Evaluation Criteria

The mesh network will be able to ferry messages from any member of the network to the gateway. This will indicate that the routing protocol is complete. This milestone can be verified by performing a large-scale test and ensuring that the gateway is receiving data from each sensor node during each wake cycle.

The home node can receive data from leaf nodes and upload these data to the web server. This can be evaluated by watching the traffic that is received by the home node and ensuring that it is getting all messages that are intended for it.

The gypsum soil moisture sensor has been tested and successfully implemented on a sensor node. This milestone can be verified by by comparing the values that our soil moisture sensor produces to the values of a few commercially available products.

We will have tested our system on a scale of around 50 sensor nodes. We will be testing the system for the reliability with which packets traverse the network, the power usage of each node in the network, and the amount that sensor nodes become out of sync with each other. This milestone can be verified by inspecting our report which will contain the results from this test.

2.11 Project Tracking Procedures

We will have weekly meetings and periodic presentations using powerpoints to make sure that everybody in our team is on track and that we're not behind the schedule to finish the project.

2.12 Expected Results and Validation

Non-Functional requirements

Reliability - We need to make sure that the web server won't lose any points of data under times of both low and high data loads. To determine whether this is true or not, we can ask all nodes to simultaneously generate a data packet and see whether the data received by the web server is complete.

Availability - We need to make sure that the web server runs at all times. We can run the web server for several months and examine the amount of downtime the server had over that time.

Reliability - The home nodes and leaf nodes run our programs on startup immediately. We can turn off and turn on the nodes to determine the reliability of the nodes to make sure that there is not any configuration required on startup.

Security - We need to make sure that only administrators are allowed to modify data. We can try to login with non-administrative accounts and see if we can access and modify only the data that account is allowed.

Data Transmission - It's necessary for us to make sure that sensor nodes are able to transmit messages to the gateway nodes. To determine that we can transmit the data from the nodes and observe whether these data can be received by the PC successfully and completely.

Functional requirements

Req 1 - The leaf nodes must be able to accurately take measurements of the soil moisture levels.

We can compare the data from our sensors with the data produced by a few commercially available soil moisture sensors. If our values are reasonably close to the other sensor's values, it is likely that our sensor is accurate. We will consider this test successful if our values are within 3% of the average of the commercial sensor's values.

Req 2 - The leaf nodes must be able to accurately record the soil temperature.

To determine whether the leaf nodes can measure and record these data accurately, we have to make trend lines based on the data we collect. Based on trend lines, we can observe whether breaking points exist in our trend lines and whether the trend is same with our assumption. We can also measure the temperature of soil with a thermometer and a sensor at the same time to ensure the data accurately.

2.13 Test Plan

Several tests needs to be conducted in our project, and theses includes the following:

1. Calibration of humidity sensor.
2. Test routing protocol by placing many sensor nodes in a field and recording how many nodes are able to accurately get their data to the gateway.
3. Test longevity of sensor nodes by doing a full scale test for a month and measuring the amount of energy left in the batteries by the end.
4. Determine the need of Polystyrene to protect the Gypsum and to stabilize the sensor.
5. Preliminary test for the accuracy of signal transmitted. (One-to-one)

Sensor Calibration: One test plan is to calibrate the humidity sensor to determine the lower and upper level of the output measurement from the sensor. This can be done by placing the sensor in different atmosphere with different RH level.

We can use two methods to control relative humidity. One is to utilize air/water vapor flow. The second method involves placing a reservoir with saturated salt solution in the chamber, which gives discrete number of values of the RH, depending on the kind of salt used. Refer to *Table 1* for details. (i.e. NaCl for 75% RH and K2SO4 for 97% RH). ("Equilibrium Relative Humidity Saturated Salt Solutions")[7]

Table 1. Salt solutions and expected relative humidity in the Vaisala´s calibrator

Salt	Water content	Expected relative humidity
15g LiCl	12 ml	11%
30g MgCl2	3 ml	33%
20g NaCl	10 ml	75%
30g K2SO4	10 ml	97%

The later method is what we are using for calibrating the sensors, and there were a few factors we had to make sure were made constant between the tests:

- Uniform temperature environment
- Two sensors per trial to insure consistency with the measurements.
- Consistent container dimensions to ensure the consistency in measurement.
- Placing the sensors in the containers without affecting the internal environment.
- Every hole or opening for passing the wiring sealed.

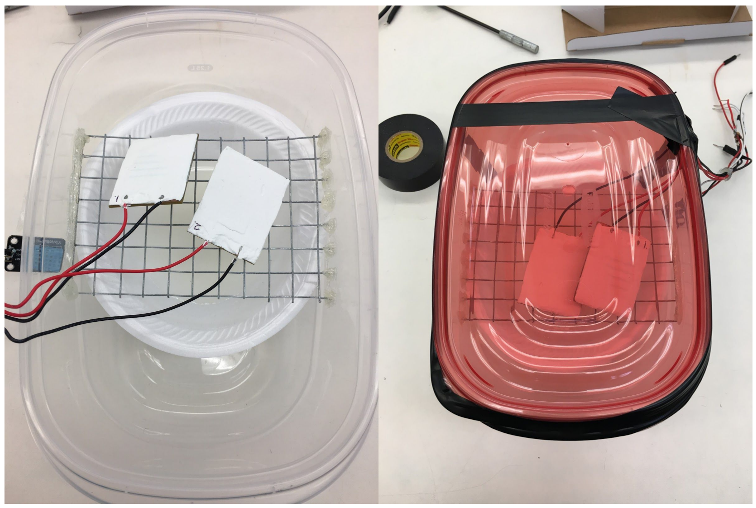


Figure 5 Calibration test experiment

Both methods require a uniform temperature environment. As already known, and illustrated in the graph *Figure 6*, a small temperature fluctuation or a temperature gradient could easily result in ±1% to ±2% error in RH. Thus, when testing, it's necessary to control the ambient temperature in order for us to have accurate measure of the RH, which is very difficult to achieve with a small tolerance, and that could be because the change of gypsum impedance is abrupt.

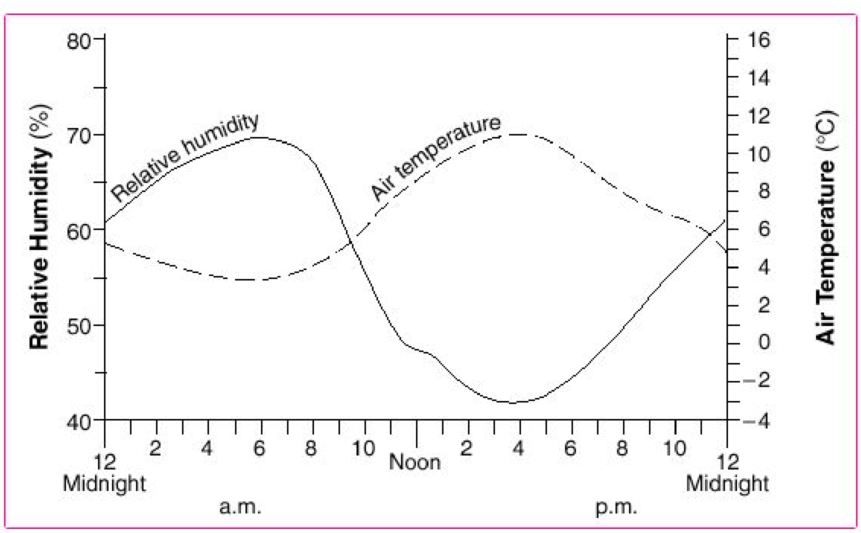


Figure 6 The relation between air temperature and relative humidity

The preliminary test has shown a satisfactory results as shown in *Figure 7*.

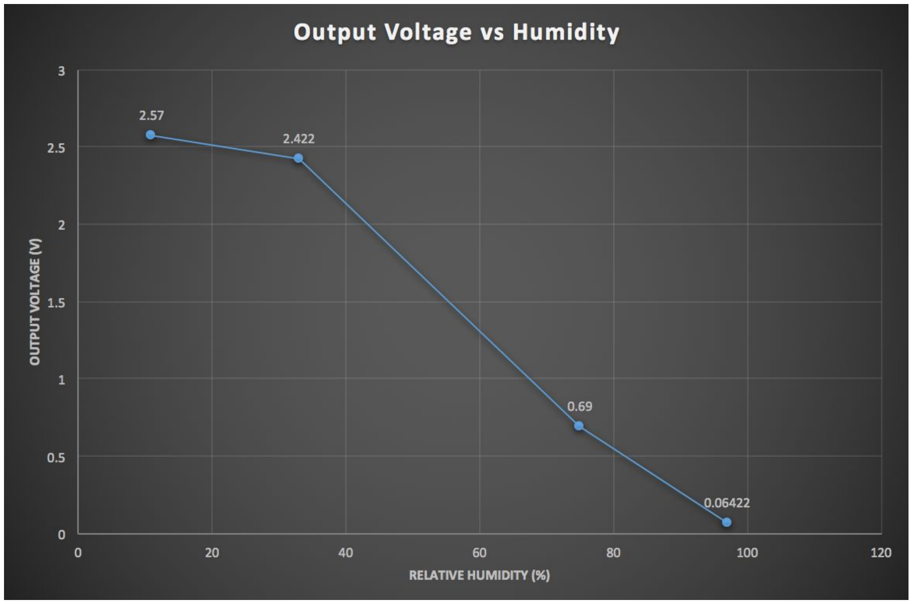


Figure 7 Calibration test results

As can be seen from this figure, the voltage output tends to deviate from the linear curve in the region less than roughly 33% relative humidity level. The mean error, averaged over all these four samples, was found to be relatively low (of the order of 10%). This is sufficient to accurately indicate the water requirement of soil and can be taken as insignificant error value.

Testing longevity of the sensor nodes

To test the communication between homenode and web server, we can send a package or some data from the homenode to the web server and obverse whether the web server can receive the data immediately and completely.

For the leaf nodes testing, we need to test whether the leaf nodes can communicate with each other and the range that the leaf nodes can communicate well. We can place leaf node with ID-1 in our laboratory and leaf node ID-5 in the another building. We can ask leaf node 1 to transmit data to leaf node 5 and observe whether there is response form leaf node 5 or not. To determine the range of leaf nodes, we can keep the communication between leaf nodes and increase the distance between two leaf nodes to test the longest distance that leaf nodes can communicate with each other without losing any data. In this test, the amount of transmitting data should be large enough.

Then we expected to test our product in a real filed owned by Sensor Web's advisor. All of device will be operated in that field naturally. We will track how our device going every day by looking at the flowchart as well. The results we got from this test will be recorded. We will improve the ability of our product based these data.

Polystyrene cover layer test

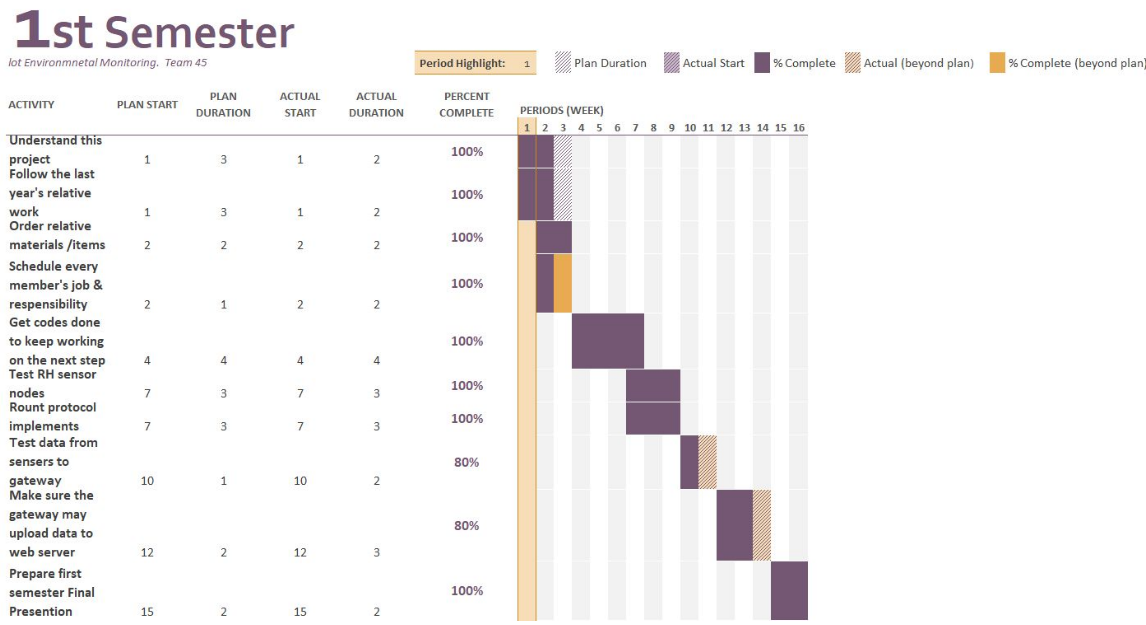
A direct connection between the gypsum used in the sensor and water can cause the electrode to take a long time to respond to a change of humidity level from high to low and hence longer time to stabilize. It can also cause some distortion to the gypsum structure. Therefore it is necessary to be stabilized by a material, which is porous for water vapour and at the same time prevents penetration of water into the gypsum.

The response time of the adsorption can take about 2 minutes, but it could potentially take long time during the desorption process. This is because there direct contact between the gypsum and the moist soil. We don't want the sensor to suffer from long response times, and so in case this situation happened in our testing, we came with an idea to stabilize it using a protective layer at the top of the gypsum. This layer or protective cavity is porous and is made from Polystyrene.

When the water vapour is trying to move from the soil through the polystyrene to the gypsum layer, the gypsum can sense the humidity but not necessarily be in touch with water. Cold surfaces is what can cause condensation, and studies show that polystyrene can less likely cause condensation and that's why we see lots of houses nowadays use polystyrene in the walls.

3. Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Understand this project	1	3	1	2	100%
Follow the last year's relative work	1	3	1	2	100%
Order relative materials /items	2	2	2	2	100%
Schedule every member's job & respensibility	2	1	2	2	100%
Get codes done to keep working on the next step	4	4	4	4	100%
Test RH sensor nodes	7	3	7	3	100%
Rount protocol implements	7	3	7	3	100%
Test data from sensers to gateway	10	1	10	2	80%
Make sure the gateway may upload data to web server	12	2	12	3	80%
Prepare first semester Final Presention	15	2	15	2	100%

Figure 8 *Project Timeline for first semester*

2nd Semester

Iot Environmnetal Monitoring. Team 45

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Run web server	1	2	0	0	0%
Investigate PCB for the leaf	1	4	0	0	0%
Node PCB order	1	2	0	0	0%
Plan case design	1	3	0	0	0%
Build sensor node with PCB	3	4	0	0	0%
System Intergation	7	2	0	0	0%
Project testing	9	2	0	0	0%
Get improvement	11	2	0	0	0%
User acceptance testing	13	2	0	0	0%
Prepare Final Presention	15	2	0	0	0%

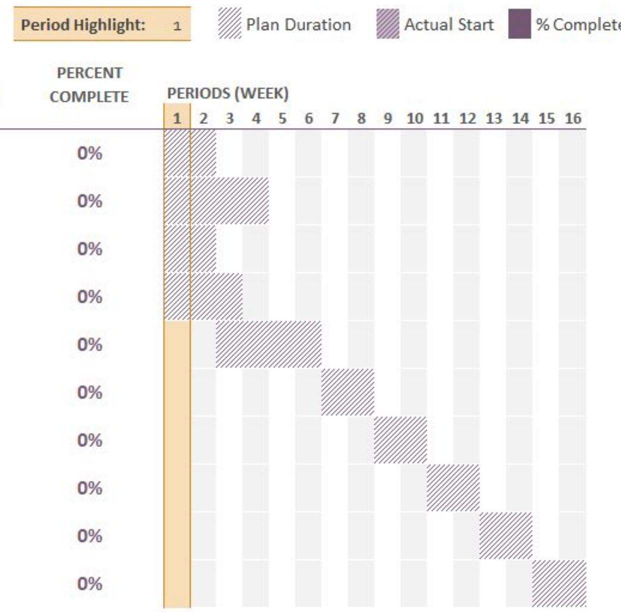


Figure 9 *Project Timeline for second semester*

This time chart is a rough plan of what our team is doing next term.

3.2 Feasibility Assessment

One the most difficult tasks for our project is power management. The leaf nodes need to send and receive data, which requires significant amounts of power. The power bank is limited, and many sensors need to be activated to send and receive data. To solve this problem, we may choose the sleep/wake cycle or find some other solutions.

One area of professional responsibility that is important to our project is the cost analysis. Our team's estimation of the initial cost of the entire project has not been determined based on the individual components we have deemed necessary. This could affect the progress of our plan of the project. However, for our team to fulfill this responsibility in the project, we have determined that the primary cost will be the hardware components. Each individual hardware component must be purchased separately. The web application server and hosting can be purchased together as a subscription model. The cost for the web application will lie only in the online hosting for the application. The cost for hosting is a monthly fee which we have estimated we will need active for remainder of the class, approximately six months. All other components necessary for the application will be free resources

The following table shows the estimate cost of our project and components

Figure

Item	Cost Per Unit	Required Count	Total Cost
Gateway	$108.00*	1	$108
Sensor Node	$13.94	~50	$697
Web Server	$30.53**	1	$30.53

Total Cost of Solution = **$835.53**

10

Estimate cost of the project

We assume that we uses 50 counts sensor nodes. The cost of gateway include the homenode(MKR GSM 1400) which is 70 dollars and a SIM card which is activated for 6 months with data cost of $5 per month.

Note: We assume our system runs for 6 months and the cost is split across 20 customers. We use the selling prices for the estimate cost, the actual base cost shall be lower than this.

3.3 Personnel Effort Requirements

Ahmed Abuhjar	● Verify that the radio signal is received and transmitted between the nodes ● Compile and the debug the code for the leaf nodes and the home node (6 hours/week)
Haoyue Ma	● Connect the circuit needed to transmit the data from the gateway to the web server. ● Program and test the code used for data transmitting from the gateway to the web server. (6 hours/ week)
Dong Xing	● Testing the radio signal transceiving between nodes with group members. ● Programming the code for both leaf nodes and the home node. ● Working on Circuit Design and keeping tracking & communicating with others. (7 hours/week)
Yuanzhe Wang	● Upload and debug the code for the leaf nodes and homenodes. ● Keep tracking the required devices from the ETG office. ● Test the range of the leaf node. (5 hours/week)
Tyler Fritz	● Ensure that the web server can receive data from the home node. ● Confirm that the database schema accounts for our project's needs. ● Ensure that there are minimum security issues in the web server and network of nodes. ● Fix the home node. ● Implement a dynamic routing protocol for packets to traverse the Wireless Sensor Network(WSN) (8 hours/week)

3.4 Other Resource Requirements

sources required

- 4 arduinos: They are used for building the sensor nodes which can collect the sensor data from the sensors
- MKR GSM 1400: It is used to build our gateway which can receive the sensor data from the sensor nodes and transmit data to the web server.
- Jumping cables: These are used to connect the NRF24N01 transceivers to the sensor nodes.
- humidity, temperature, and other sensors for Arduinos: They are used to collect the humidity, temperature, and other data.
- NRF24N01 transceivers: They are connected to the sensor nodes which can help sensor nodes communicate with each other.
- Battery holders and batteries: They are used to provide the needed power for our sensors.

3.5 Financial Requirements

It’s hard for us to determine the cost right now because we may use the different power for each individual part in this system. The following image shows the cost from old project. we may change the cost later. (reference 7)

Op. Node Power and Cost Analysis

Power Analysis

			power consumption		voltage	Current	frequency	Pdynamic	Pstatic
			Atmege 328	ON	4.5	2.00E-04	1.60E+07	1.60E-02	9.00E-04
			NRF24L01+	ON	3.3	1.50E-02	1.60E+07	8.45E-04	0.0495
			Atmege 328	SLEEP	4.5	7.50E-07	1.60E+07	0	3.38E-06
			Ptotal=Pdynamic+Pstatic						
			assuming	time (min)	amount per	total time/day (sec)			
			atmega ON	5	2	600			travel time 3 seconds
			atmega OFF	1429.8	1	85788			100 nodes
a atmega	0.5		NRF24L01+	0.1	2	12			
a tranciever	1								
assuming 50% activity factor,									
worst case capacitance load			energy	Joules/day	power				
tranciever drives 16pF load			atmega ON	1.01E+01	2.82E-03				
Atmega ON drive 10uF			NRF24L01+ (	6.04E-01	1.68E-04				
Atmega OFF drive nothing			atmega OFF	4.05E-05	1.13E-08				
			Total Power		2.98E-03	Watts (J/s)			
				capacity (mA	voltage(V)	amount			
			AAA	1140	1.5	3			
			total	3420	4.5				
			Wh	15.39					
			Total Time	5.16E+03	hours				
				2.15E+02	days				
				7.16E+00	months				

Cost Analysis

Parts per node		
Parts	price	amount
Male connector	0.23	2
Female connector	0.41	2
Switch	0.58	1
Atmega 328p	2.11	1
16MHz Clk	0.6	1
22pF Cap	0.34	2
1k Resistor	0.1	1
ICSP program pins	0.31	1
AAA batteries	0.295	4
NRF24L01+ tranciever	1.199	1
AAA battery holder	2.02	1
PCB	0.392	1
N-MOS	0.78	1
3.3V Linear Reg.	0.43	1
TOTAL:	11.661	

4 Closure Materials

4.1 Conclusion

We are setting out to solve the problem that monitoring large expanses of land is a very costly endeavor. Our solution will be a wireless sensor network that will provide better data than our competitors at a much lower cost. A soil moisture sensor and humidity sensor will be developed and equipped on leaf nodes. Each node will collect data from sensors which will be sent to the home node. The project will have a website that will display the data that be uploaded by the home node to our clients in a simple and friendly way. We are working on the nodes connection.After that we are going to find a good solution for power supply then we are ready to test our products in the field. We have a very strong head start because we are continuing the work of a previous senior design group. This fact along with our passion for solving this problem make us confident we will be successful in developing this system.

4.2 References

[1] Miner, Andrew. "Networks 2." Lecture.

[2] Tuttle, Gary, Barebones Arduino.Print

[3] TempuTech, "Wireless Sensor Monitoring," TempuTech, [Online]. Available: http://www.temputech.com/26-home/slider/113-wireless-sensor-monitoring. [Accessed 21 02 2017].

[4] Banner Engineering Corp. "Wireless I/O & Data Radios | Products for Industrial & Process Automation." Banner Engineering. Banner Engineering, n.d. Web. 21 Feb. 2017.

[5] The 5 Step Problem Solving Approach, "eba," eba, 2016. [Online]. Available: http://www.educational-business-articles.com/5-step-problem-solving/. [Accessed 21 02 2017]. (From the old group)

[6] Scientific Research Publishing. "Development of a Low-Cost Internet-of-things (IOT) System". (2017, July 4). Web. 27 Sep. 2018 [Online] available at https://file.scirp.org/pdf/AIT_2017070316282178.pdf

[7] *Omega.Com*, 2018, https://www.omega.com/temperature/Z/pdf/z103.pdf. [Accessed 3 Nov 2018].

[8] Perkins, Charles E, and Elizabeth M Royer. Ad-Hoc On-Demand Distance Vector Routing. University of California, Santa Barbara, people.cs.ucsb.edu/ebelding/sites/people/ebelding/files/publications/wmcsa99.pdf.

[9] Bhondekar, Amol & Kaur, Harmanpreet. (2015). Routing Protocols in Zigbee Based networks: A Survey.

4.3 Appendices