Home Energy Management

EML 4911C-Senior Design- Fall 2015

Midterm II Report

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Foundation for Engineering Education for Distributed Energy

Advisor: Dr. Faruque

faruque@caps.fsu.edu

Department of Electrical Engineering

Instructor: Jerris Hooker

Jh09c@my.fsu.edu

Team 8 Members:
Dillon Wiggins
Pablo Aguirre
Juan Jose Ospina
Ivan Remete
Michael Garcia-Rivas

Department of Electrical Engineering, Florida State University, Tallahassee, FL

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Project Statement

The energy industry is rapidly approaching a significant bottleneck in the supply of energy causing a possible energy crisis in the world in the next few years. The problem is not essentially how much power is generated, but how much power get wasted or misused in a certain way primarily due to the lack of a properly energy management system that will allow the control and monitor, in real time, of the energy resources. The management of real-time pricing of the demand is postulating itself as a real alternative that could help stable the supply and demand curve of the energy generation industry.

According to Brattle Group, a leading consulting firm, during the power crisis in the Western U.S. in 2000/01, a demand response program would have helped contain the energy crisis in California. If real-time pricing had been offered to large commercial and industrial customers, peak demand would have fallen by 2.5 percent, resulting in a drop of 18 percent in wholesale market prices [1].

Therefore, utility companies are strongly considering the implementation of Real Time Pricing (RTP) in order to regulate the load demand on their systems. The concept of RTP describes how price will change at a certain frequency based on demand and generation. Likewise, RTP will make the use of renewable energy sources and other type of technologies more suitable due to the fact that production of energy could be segmented into optimal times, i.e. only generated when demands exceed the supply. RTP will help smooth the load curve and take full advantage of these resources.

With the implementation of our Home Energy Management (HEM) System and the advantage of RTP provided by electric utility companies, consumers will have the ability to adjust their energy usage in order to reduce their electricity bill.

State-of-the-Art Technologies

With the rise of new technologies such as smart grids, smart meters, and smart appliances, smart homes are being proposed as the next solution for utility companies and home owners alike. With smart meters, utility companies are able to monitor residential and commercial loads in real-time and effectively charge consumers accordingly. Smart homes will be the next integration between the utility companies and the consumer, where the utility company will benefit in lowering its electrical peak production (thus making generation more efficient and viable) and consumers will benefit in lowering their electric bill.

Currently, there are many proposed (as well as currently used) ideas which are mostly aimed for the utility company. Our design in contrast is completely consumer based. With these new technologies, the utility companies will implement demand-response (DR) programs, where different payment methods are implemented for the consumer. DR programs fall into two categories: Dynamic Pricing (DP) and Direct Load Control (DLC).

Power Line Communication (PLC)

PLC is a method of communication protocol that uses electrical wiring (AC or DC) to carry both electrical power and data. PLC send out higher (than 60 Hz) frequency signals over power lines and then get filtered out at the end. PLC is used in electrical transmission, distribution, home networking, and automotive uses. For home networking uses it is called Broadband over Power Line (BPL) which allows for high-speed internet access through existing power lines. Since extensive infrastructure is already present, it offers a great benefit to using

BPL over RF. There are many pros as to using PLC's over RF communication, yet the cons outweigh the pros. The pros for using PLC are as follows: the data speeds are extremely fast (ranging from 90Mbps to 200Mbps), since it uses power lines, it will have no trouble in communicating in various locations from the home where RF can fail. And lastly like already mentioned, the infrastructure is already present.

Although the pros may seem favorable, RF communication surpasses PLC due to the following cons: the hardware for PLC is more expensive, it does not function with filtering devices (surge protectors, power strips, and AFCI's), it is dependent on the electrical wiring in the house itself (if the house is improperly wired the breakers will trip and the system will fail), and lastly, transient noise (ON/OFF switching) degrades the performance of PLC and can cause the system to fail.

Dynamic Pricing	**Direct Load Control**
DP consists of real-time pricing (RTP), where the utility company bases (e.g. Every 15 min) the electrical rates according on the real-time load demand. With the use of DP, the utility aims to shift the peak and off peak prices to smoothen out the load curve.	With DLC, utilities will have full control of the consumer loads. With this program, utility companies never risk in having an electrical outage (brownout or blackout) and can level out the load curve when unexpected spikes occur.

Current technologies

Most consumer load control technologies do not incorporate the utility company, since DR technology has not been incorporated yet, meaning home automation are basic on and off switches. Since the electrical rate is fixed, home automation only works when the user has forgotten to turn off his/her appliances when they are not at home to save money.

In some states such as California [2], Arizona [3], and Oregon [4] utility companies have incorporated time-of-use programs (TOU), where the electrical rate change based on the time of the year (e.g. summer and winter, when loads are higher) or based on weekdays and weekends. With these programs, the consumer can start taking advantage of smart appliances.

Current companies

One major company who has started to implement these current technologies is Trilliant [5], who has helped implement (TOU) billing for Hydro One in Ontario, Canada. Trilliant has also helped implement solutions for other leading utilities companies such as Centrica's British Gas and Iberdrola USA's Central Maine Power. Currently, Trilliant is working in implementing DR for utility companies, by installing smart meters, and setting up a communication infrastructure.

Future and proposed solutions

Since DR programs are new, new ideas arise to make the generation and distribution of electrical energy more efficient for the utility companies, as well as make it more economic for the consumer. Like stated before, these proposed systems are more beneficial for the utility side, yet the consumer does also acquire some benefits. Two (concept) systems will be briefly covered, to which our design can be compared too. One system was developed by Trilliant and the other proposed in Control Mechanisms for Residential Electricity Demand in SmartGrids (CMRED) [5].

Trilliant System

Trilliant will implement utility managed programs, where the consumer can choose different payment plans with the utility company. One programs consist of the DLC, where Remote Appliance Controllers (RAC's) control the state of the appliance (ON/OFF) based on RTP. The RAC's will manage loads such as water heaters, pool pumps, and air conditioners and can be programmed for DLC or DP. The RAC's will receive the RTP information from smart meters (which connect to the utility company using PLC) via home are network (HAN) and near-me area network (NAN). An interesting take on distributed networks that Trilliant proposed is with the use of electric vehicles and plug-in hybrid vehicles. Since both vehicles have a large energy capacity, they can be used as a supply of energy when the RTP is high, and charged when RTP is low.

CMRED

In the system proposed by CMRED, it is assumed that all appliances in the consumer side (being residential or commercial) are smart appliances which use energy management controls (EMC's). Similar to Trilliant, CMRED will receive RTP data via the smart meter (through HAN) to control the EMC's every 15 min. The EMC's will have two features, one that programmed based (which uses DLC) and one stand-by (user) based.
CMRED also proposed an interesting take with this new technology, where it will use DLC to a 'collection of neighboring homes' to reduce the peak demands when it is critical.

Design and Analysis

Design Requirements

The energy management system proposed needs to be able to position itself as a real competitor that could enter the energy management industry and take on the responsibilities of handling energy resources in efficient and valuable ways. In order to fulfill the requirements needed in the development of an efficient management system, the HEM team will focus on the design of the requisites and product specifications presented below:

1. Development of a system that will allow the real-time control and automatic adjustments of energy usage based on predefined settings provided by the user.
2. Development of load controller that will be responsible of controlling and monitoring the energy consumption of each assigned load.
3. Development of a main controller that will act as a local manager for controlling the communication and load interaction.
4. RF/Wireless will be the primary technology used for the communication between the main controller and the load controllers.
5. An algorithm will be develop to control all the loads according to real-time pricing provided by the utility company. Algorithm will process the information and decide which loads can be turn off based on consumer input settings stored on the website.
6. A low cost product is necessary for the correct implementation of the design in order to maintain it as a viable option for the market. This resulted in the use of low-powered microcontrollers and devices that can fit the budget.
7. Development of a website/web application that will act as the user interface and data server containing all the information regarding the usage of the loads. Also, the web application must be the primary connection to the RTP information provided by the utility company.

A throughout analysis on the main characteristics of the HEM system must be performed, before a final design is proposed, in order to find out if this approach is a feasible solution. According to the needs and requirements explained, it can be observed that some of the requirements are more important than others when completing the final design of the project. The needs were evaluated using the comparison matrix showed in Table 1. The concept for the design was focused on four main points which can be used to compare the viability of the whole concept.

- High Performance
- Low Cost
- Power Consumption
- High Reliability

	High Performance	Low Cost	Power Consumption	High Reliability	Geometric Mean	Norm. Weight
High Performance	1	5	5/3	1	1.70	0.36
Low Cost	1/5	1	1/3	1/5	0.34	0.07
Power Consumption	3/5	3	1	3/4	1.08	0.23
High Reliability	1	5	4/3	1	1.60	0.34

Table 1 Comparison Matrix

As seen on the comparison table, the top points to take into account when developing the concept proposed are high performance and high reliability. In other words, the design must be catalogued as a reliable and efficient system. The other two remaining points were also taken into account when designing the project specifications but were considered as less important when deciding for an overall design.

Following this criteria was essential for the production of the final design proposed, in which most of the needs are achieved by:

- High performance: is mainly achieved by the use of high performance microprocessors and controllers.
- High reliability: is achieved by using consistent and reliable software deployed on high performance hardware.
- Power consumption: is achieved by using low power consumption controllers.
- Low cost: is achieved by using moderate price hardware which is highly reliable and low cost compare to other options.

It's important to note that an advantage of the design over other concepts, like PLC (Power Line Communications) is that this concept is designed to be easily deployed by the client with simple configurations done through the web application.

Design Description

The energy management system proposed can be described by separating each of its components into smaller pieces, like the main controller, load controller, web application, and HME automation algorithm. The most important parts of the system are described below.

1. **Main Controller:** The main equipment installed in the user home/environment.

Main tasks:

- Controlling all the load controllers within range.
- Executes the HEM algorithm developed that will allow the automation in the control of energy consumption.
- Gateway between the web application and the load controllers. The real-time user interaction commands are decoded here and passed to the load controllers.
- Receives data, like the RTP or user commands, from web application.

The main components used for the development of the main controller, with all their specifications are described below.

Components:

- **Beagle Bone Black:** embedded computer designed by Texas Instruments.

Characteristics	Specification
Processor	AM335x 1GHz ARM® Cortex-A8
RAM	512MB DDR3 RAM
Storage	4GB 8-bit eMMC on-board flash
Connectivity	Specification
	Ethernet
	SPI (Serial Peripheral Interface)
	HDMI
	GPIO

Table 2: Beagle Bone Black Specifications

Figure 1: Beagle Bone Black

- **NRF24L01+:** Transceiver used for creating the communication scheme between the main controller and the load controllers. Developed by Nordic Semiconductor.

Characteristics	Specification
RF Technology	2.4 GHz ISM Band Operation
Modulation	1 or 2 MHz Bandwidth
Information	Dynamic Payload 1 to 32 bytes

Table 3: nRF240L01+ Specifications

Figure 2: nRF240L01+

- **5V DC Power Supply:** Standard 5V DC power supply in charge of powering the Beagle Bone Black.

2. **Load Controller:** Equipment that must be connected to the loads that the user wants to control.

Main tasks:

- Receives commands from the main controller in order to perform manipulation of loads.
- Sends back data to the main controller regarding the usage of the specific load.
- Controls the flow of electricity, ON/OFF action, by controlling relays that manage the flow of electricity.
- Load controller will be separated in to two or more types: regular load controller, which can be installed to any load that wants to be controlled, and a special thermostat load controller which will have additional functions regarding temperature measurements.

The main components used for the development of the load controller, with all their specifications are described below.

Components:

- **NRF24L01+:** Transceiver used for creating the communication scheme between the main controller and the load controllers. Developed by Nordic Semiconductor.
- **5V Relay Module:** Relay module that controls the flow of electricity, facilitating the ON/OFF action control on the system. Module reference SRD-05VDC-SL-C.

Characteristics	Specification
Max Current	10 [A]
Max DC Voltage	30 [V]
Max AC Voltage	250 [V]

Table 4: 5V Relay Specifications

Figure 3: 5V Relay

- **MSP432P401R:** Microcontroller used for the control of the 5V relay module, control of the communication protocol with the main controller using the NRF24L01+ transceiver, and data acquisition from temperature sensor and current sensor used to monitor the specific load behavior.

Characteristics	Specification
MCU	48 MHz 32-bit ARM Cortex
Power	95 [uA]/MHz Active Operation 850 [nA] Standby Operation
Flash RAM	256 KB 64 KB

Table 5: MSP432P401R Specifications

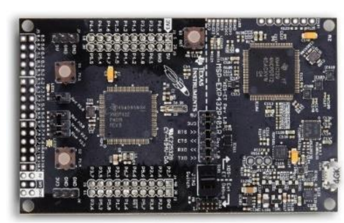


Figure 4: MSP432P401R

- **Temperature Sensor:** LM74 Delta-Sigma analog-to-digital converter. Sensor used for the calibration of the thermostat load controller.

Characteristics	Specification
Supply Voltage	2.65 [V] to 5.5 [V]
Supply Current	Operating: 265[uA]
Temperature Accuracy	–10°C to 65°C ± 1.25°C (max) –55°C to 125°C ±3°C(max)

Figure 5:LM74 Temperature Sensor Specifications

Figure 6: LM74 Temperature Sensor

- **Current Sensor:** 5600 Series Current sensor. 10 [A] max current. Sensor used for determining if a load is being actively used or not.
- **5V DC Power Supply:** Standard 5V DC power supply in charge of powering the microcontroller.

3. **Web Application:** Main way of interaction between the user and the system. User interface for the energy management system.

Main tasks:

- Provides the user with the user interface (UI) used for the real-time control of the loads.
- Sends data, commands, and RTP information to the main controller.
- Stores user specific information and gives back feedback to the user about the energy consumption on their own system.
- Contains the real-time price provided by the utility company and sends the information to the main controller in order to execute the automation HME algorithm.
- Gateway between the utility company and the user of the system.

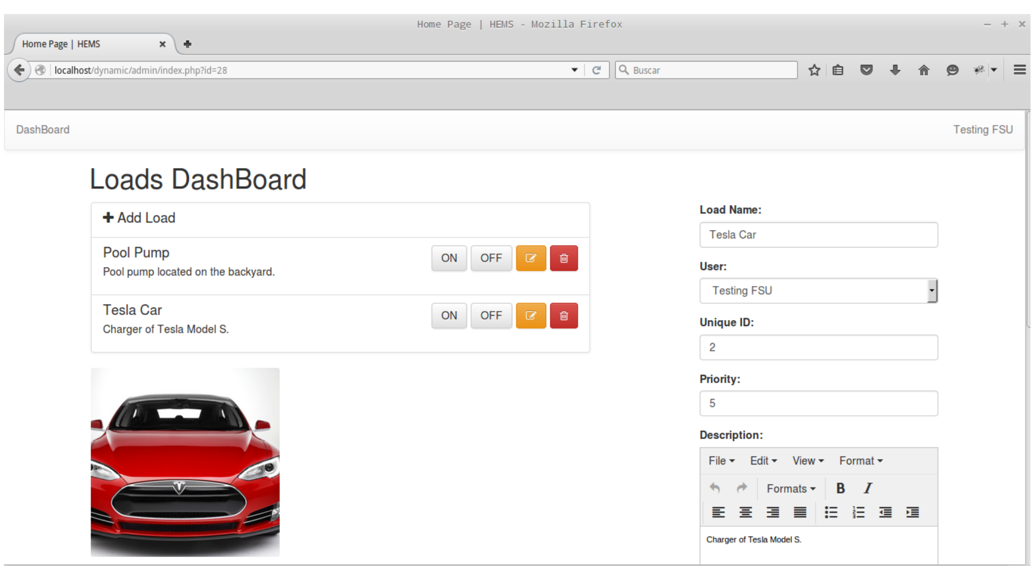


Figure 7: Web Application Interface

4. **Algorithm:** software solution in charge of automating the control of loads based on the RTP information given by the utility company.

Main tasks:

- Automatic control of the loads based on the RTP information given by utility company.
- Performs discrimination of the loads depending on the priority status given by the user through the web application.
- Main software in charge of controlling the loads from the main controller.

A detailed breakdown description of how these components interact with each other in the energy management system proposed is given later on the breakdown section of the report.

Design Schematic

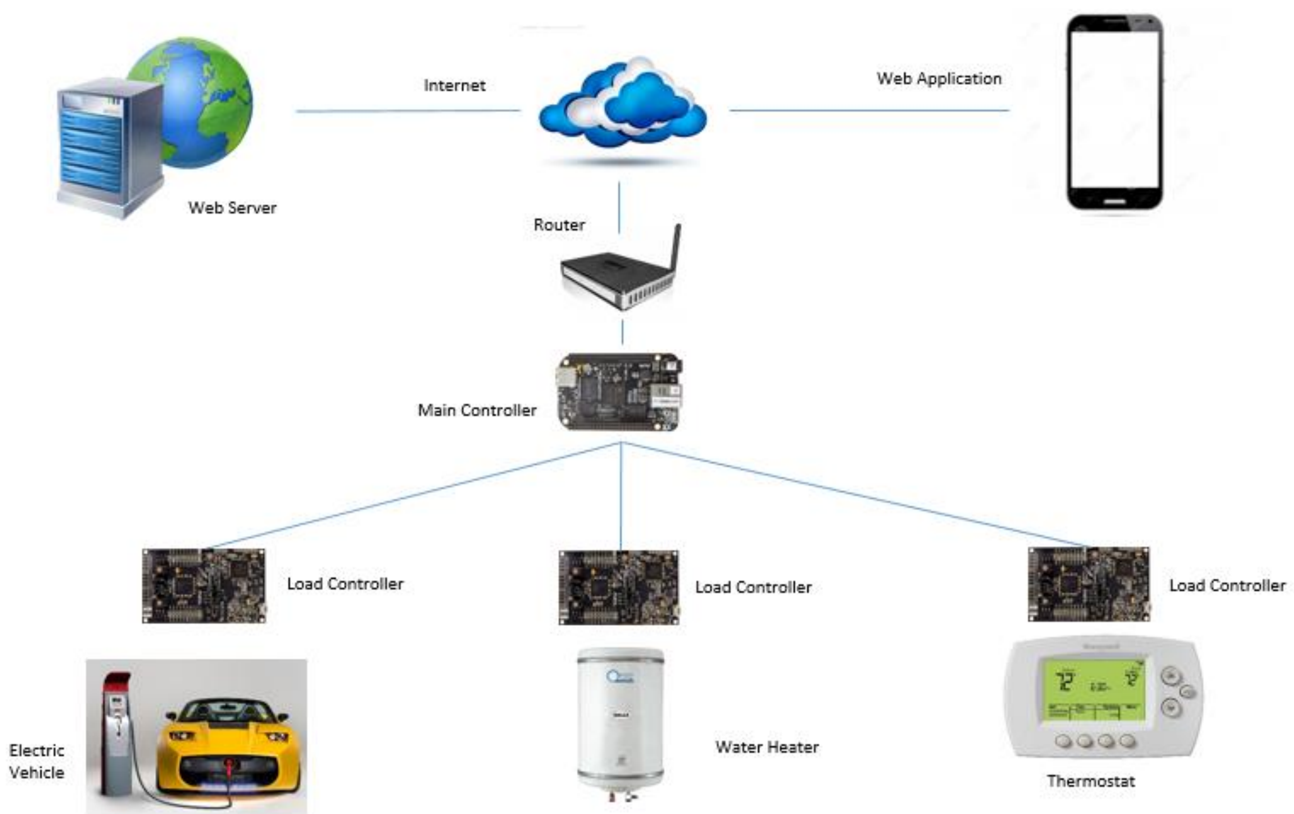


Figure 8: Displays the Top-Level Design of the Project

Figure 1 shows a depiction of the schematic representing the complete HEM system and the interconnection between all its components. As seen, the flow of information starts at the top of the schematic, essentially in the web application, which contains all the user information, pricing information and other variables that affect the algorithm executed on the main controller.

When the information arrives at the main controller, it executes the HEM algorithm which is in charge of deciding the commands that will be sent to the load controllers according to the user defined specifications.

Finally, the load controller will receive the command given and perform the specified action required by the user or the real-time price algorithm. The load controller will be able to send important information back to the main controller stating the current status of the specific load.

Figure 9: Displays model home with the install system

Figure 2 depicts a possible real life implementation of the HEM system proposed. Possible potential home loads are shown on the image, including an electric car in the garage, a pool pump located next to pool, a refrigerator in the kitchen, the thermostat load controller in the living room, and televisions in each bedroom. The layout of the system is also presented by showing how the main controller will need to be strategically located at the center of the home in order to have the best signal reception across the house.

Breakdown Description of the HEM System

HEM Algorithm

In order for the HEM System to save user money, it will rely on an algorithm. The algorithm will utilized the data the user enters in the website for all calculations and decisions. Since this is just the beginning of the project, the user will have to enter the load usage data on the website. Ideally in the future the system will include metering at each load controller.

Information needed by the HEM algorithm. This information will be input by user using the website:

1. **Load Controller ID:** used by main controller to identify which load is connected to each load controller.
2. **Load Power Consumption:** this should be an estimate of the total power consumed by the load on average (usually provided by manufacturer)
3. **Priority for Each Load:** based on a 1-10 scale. Priority 1 are first loads to be turned off, and priority 10 loads are only turned off when price is at a maximum.

4. **Maximum Desired Electric Bill:** the maximum amount of money the user wants to spend per month. User should determine the price based on past bills. Due to usage changing throughout the season this price should be updated every other month. Future product may take care of this based on current month and weather forecast.
5. AC schedule and maximum deviation from scheduled temperature (ex. ± 5ºF)

The algorithm starts by retrieving the required data from the website, this includes the current real time price, the load data entered by the user, and the priorities for loads. Next the algorithm will communicate with the load controllers to determine all of the loads currently in use. Utilizing the real time price and the load data, the algorithm will then calculate the approximate cost of energy being utilized.

Once the price of energy currently being used is calculated, the algorithm will compare it to the price specified by the user. Equations 1 through 3 show how the current usage cost is calculated and compared to the monthly price specified by the user. As of now, the calculations are done based on a 5 minute interval, but this could easily be increased or decreased in the future.

$$maximum\ hourly\ price = \frac{monthly\ price}{31\ days} * \frac{1\ day}{24\ hours} = \frac{monthly\ price}{744\ hours}$$ **Equation 1**

$$maximum\ 5\ minute\ price = \frac{monthly\ price}{744\ hours} * \frac{1\ hour}{60\ minutes} * 5\ minutes = \frac{monthly\ price}{8928}$$ **Equation 2**

$$current\ usage\ price = sum\ of\ load\ usage\ [kW] * 5\ minutes * RTP\ \left[\frac{\$}{kWh}\right] * \frac{1\ hour}{60\ minutes}$$ **Equation 3**

Once the current price is compared to the maximum price the algorithm will start deciding what loads need to be turned off. The bullet points listed below show what conditions effect what loads.

- Current usage price is greater than 25% of the maximum specified price or current RTP is 25% of yesterday's maximum price
  - Loads with priorities 1 – 4 will be turned off.
  - AC will be adjusted 1º - 2º F
- Current usage price is greater than 50% of the maximum specified price or current RTP is 50% of yesterday's maximum price
  - Loads with priorities 1 – 7 will be turned off.
  - AC will be adjusted to maximum deviation
- Current usage price is greater than 75% of the maximum specified price or current RTP is 75% of yesterday's maximum price
  - Loads with priorities 1 – 10 will be turned off.
  - AC will be adjusted to maximum deviation

This is just the base of the algorithm. The algorithm will change as testing is done. Both simulations and real world testing will be performed to validate the correct operation of the algorithm. Ideally the algorithm would be able to learn the consumer's habits and adjust loads based on this data, but due to time constraints and the need to present a final product by the end of spring 2016, this is not implemented in the current design. Figure 9 is a flow chart representing some of the details of the load control algorithm.

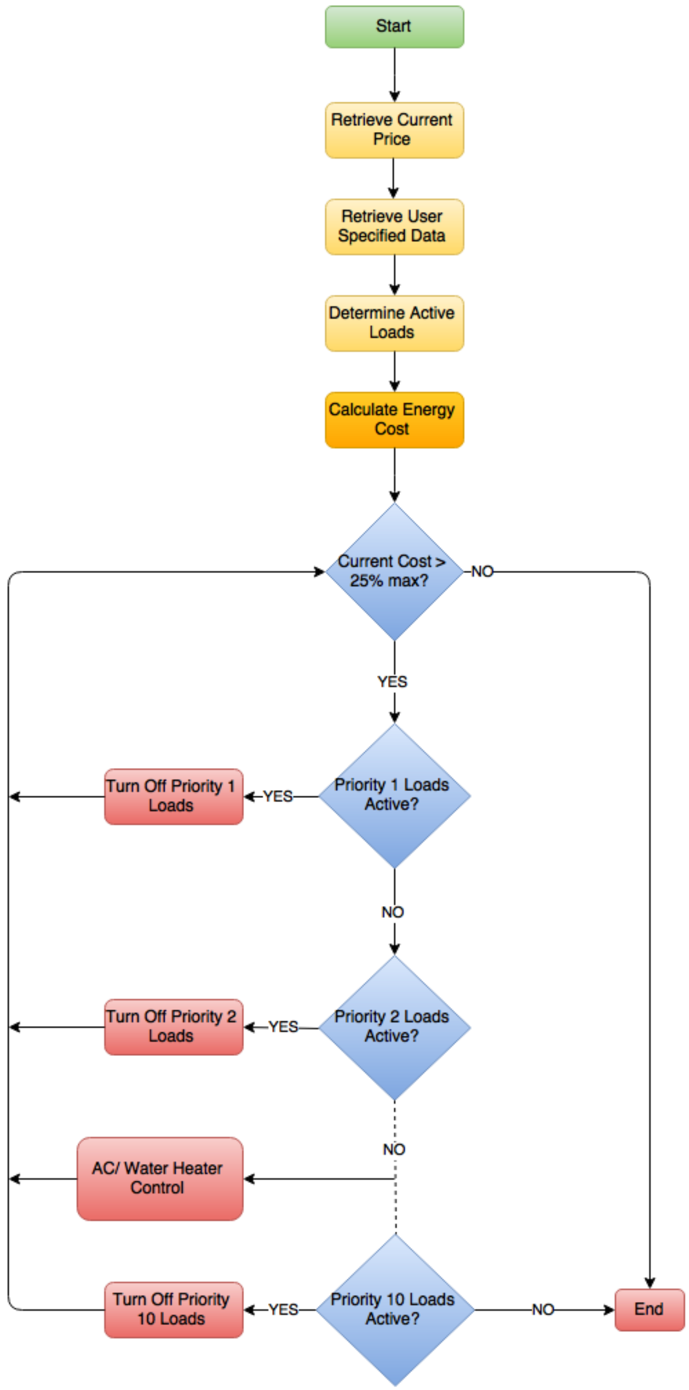


Figure 10: Load Control Algorithm

Outer Network (Web Application <- -> Main Controller)

The network design for the HEM system can be separated in two main sections that describe the flow of information through the system. These two main sections are:

1. Outer Network Connection.
2. Inner Network.

In order to provide a detailed description of the outer network design developed in the system, a further division of its main components must be done. The analysis of the outer network will be done explaining all the elements that will be implemented at the end of the project and how all these modules need to work in order to achieve the correct operation of the system.

1. **Web Application / Web Server**

The web application of the design will be hosted using a hosting service company. When the website is hosted using this service, the most important data needed is the public IP where the website will be hosted and the DNS (Domain Name Service), which is in charge of assigning a domain name, or URL, to the public IP provided.

Ex:
Public IP: 8.20.45.180
URL: energymanagement.com

The web application is being developed using a server-side programming language (PHP) for real-time interaction, socket connection, and SQL database access. Client-side programming languages (JavaScript, HTML5, and CSS) are being used for the creation of the website and overall structure and design of the web application.

2. Main Controller

As explained before, the main controller will consist of Beagle Bone Black connected to the internet via Ethernet connection or Wi-Fi connection. The connection between the main controller and the web application will be done using a TCP socket connection between the two public IPs. Figure 10 shows the simple schematic explaining the real-time socket connection needed between these two modules. As seen, the needed information to bind these two IPs, using the socket specified, is the public IPs and the TCP ports used for the connection.

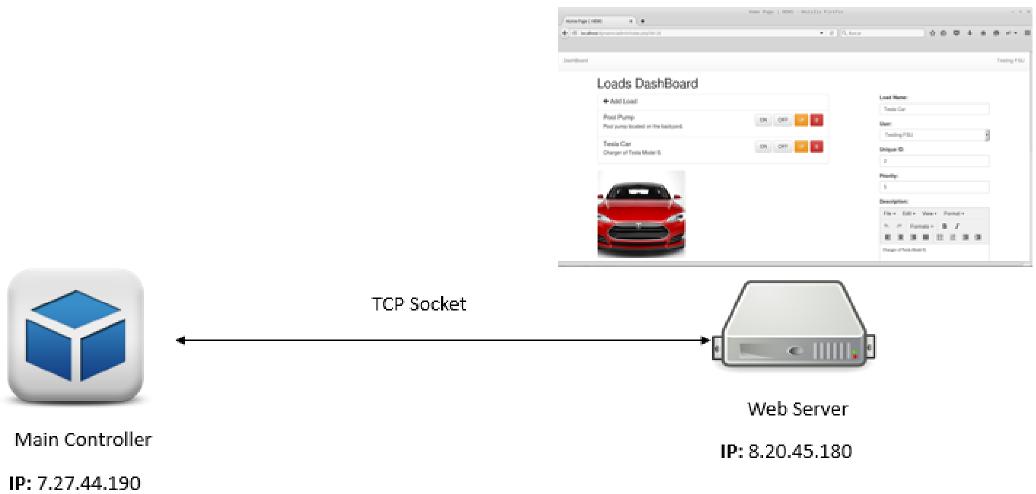


Figure 11: Socket Connection

Unfortunately, this ideal setup is very improbable, since most home or domestic users are provided with dynamic IPs (not static as the webserver) by their own ISP (internet service provider). This issue, together with the fact that most home users make use of a router (with a firewall) to connect to the internet, make difficult the TCP connection between the two IPs. Figure 11 shows how normal home users use their router to navigate the internet.

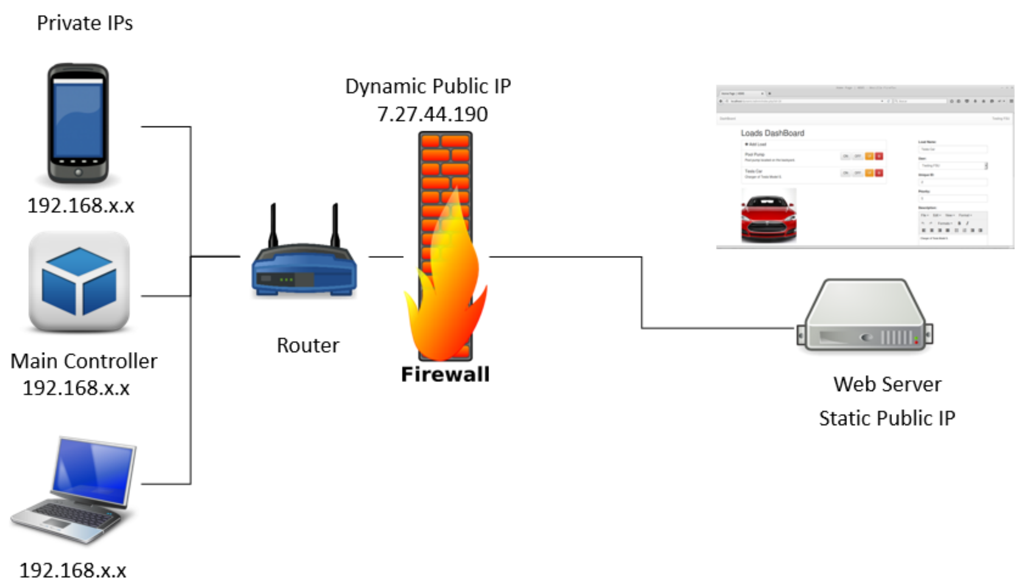


Figure 12: Normal Schematic of Home User Connection

As seen on this figure, there are two essential problems that need to be addressed for successful connection of the TCP socket. It's important to note that security is not a main concern on this implementation, yet. These problems can be summarize as:

- How to route the private IP of the main controller to the public IP of the connection.
- How to solve the dynamic IP issue, so that even if the IP changes, the connection is not lost.

The first problem arises from the fact that the webserver must be able to send information directly to the private IP of the main controller on the LAN (Local Area Network) of the user. This can't be achievable without the use of Port Forwarding. Port forwarding is defined as an application of NAT (network address translation) that redirects all communication requests from one IP address and port number to another, essentially the network gateway router.

By configuring port forwarding on the home user router, the main controller can be port forward to the public IP and the main controller will be "exposed" to the internet, allowing the TCP connection to happen.
This connection works correctly until the Dynamic Public IP of the home user changes. This change can't be predicted since it could happen at any time, and only the ISP has full control of this action. So, in order to solve this issue, the design must introduce the use of another technology called Dynamic DNS.

Dynamic DNS (DDNS) is, in essence, a method for the automatic update of the name server in the DNS with the active DDNS configuration present on the hostnames or host addresses. In other words, this is the method in charge of assigning a logical name, like "*logical.ns01.info"*, to the public dynamic IP assigned to the home user by the ISP.

By using this method, the configuration of the TCP socket connection doesn't need to be assigned using static IP addresses, since the use of logical names give the advantage of referring to this name when needed, which at the same time is being assigned dynamically to current IP address used by the home user.

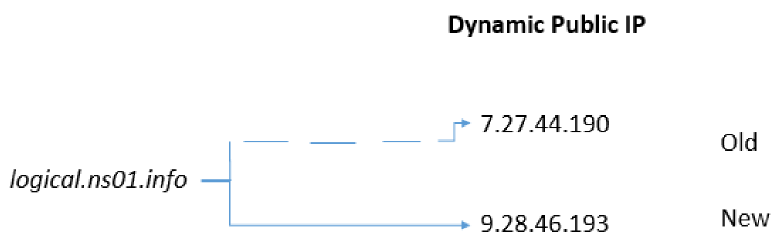


Figure 13: Example of Dynamic IP change

After the configuration of these modules, the TCP connection can be successfully done without any issue, other than possible security breaches caused by intrusion in the connection. The configuration of these modules, essentially the port forwarding and DDNS assigning, should be offered as a simple configuration done by the client using the main application of the HEM system. This configuration is aimed to be a straight forward, easy to follow, setup steps that any user could follow without any significant problems.

Inner Network (Main Controller <- -> Load Controller)

NRF24L01+ Transceiver Settings

To have both transceivers communicate with each other, the transmitter (TX) and the receiver (RX), we need to initialize all the settings for each transceiver before sending or receiving data. In the following table, we can use any address for the receiver as long as the transmitter knows the address.

Address	0xE7D3F035FF
Channel	Depends which RX the TX is sending info to
Data Rate	250 kbps
Dynamic Payload	YES
Power Amplification (PA)	$(11)_b$

Table 6: nRF24L01+ Transceiver Settings

1. **Address:** This address tells the transmitter which receiver to send info to. It doesn't matter what address you choose for each receiver as long as they are different so that the information is sent to only one receiver. If two receivers share the same address the transmitter sends data to both, so essentially they receive the same data.
2. **Channel:** The channel information tells the transceiver which RF frequency the TX needs to send the information on. The NRF24L01+ operates between 2.400 and 2.525 GHz. The RF channel sets the frequency using the following equation:

$$F_0 = 2400 + RF\_CH\ [MHz]$$ **Equation 4**

RF_CH is the channel used; for example, if the channel were to be 76, the frequency used to transmit data would be 2.476 GHz.

3. **Data Rate:** Data Rate specifies the data rate used in transferring information. For our project, we do not need to worry about high data rates because we are not sending a lot of information to each controller so we specify the Data Rate to be 250 kbps.
4. **Dynamic Payload:** The Dynamic Payload tells the NRF24L01+ if the payload length in the packet needs to be defined or dynamically acquired. To reduce the possibility of error, we have the Dynamic Payload bit set to YES (or ON) so that a payload length is not necessary.
5. **Power Amplification:** The Power Amplification setting sets the output power from the NRF24L01+'s power amplifier. For our application, we need its max power potential so we set it to 0dBm using $(11)_b$ as seen in the following table.

SPI RF-SETUP (RF_PWR)	RF output power	DC current consumption
11	0dBm	11.3mA
10	-6dBm	9.0mA
01	-12dBm	7.5mA
00	-18dBm	7.0mA

Table 7: PA Control Table

Conditions: VDD = 3.0V, VSS = 0V, TA = 27ºC, Load impedance = 15Ω+j88Ω.

Each of these settings are equally important for our communication setup for the NRF24L01+ but it is important to note that we also need to determine which NRF24L01+ is the TX or the RX which is determined if we are sending data to or from the Beagle Bone Black and to or from the MSP432. We plan to send information both ways so each of these settings need to adjust constantly while running the HEM.

Data Packet Architecture and ShockBurst™ Technology

Information sent between NRF24L01+ is wireless and therefore not seamless or error free. Nordic Semiconductors, the company that produces the NRF24L01+, knows this and developed the Enhanced ShockBurst™ technology to aid users in sending data wirelessly. Enhanced ShockBurst™ is a packet based data link layer that provides many handy features such as 1 to 32 bytes of dynamic payload, automatic packet handling, automatic packet transaction handling, and 6 data pipe Multiceiver for 1:6 star networks.

The automatic packet transaction handling is an especially helpful feature included in the Enhanced ShockBurst™ technology. The automatic packet transaction handling works as follows:

1. It begins by transmitting a data packet from the transceiver (TX) to the receiver (RX).
2. Then, the TX is then set to receive mode to wait for acknowledgement packet (ACK packet).
3. If this data packet is received by the RX, the RX sends the ACK packet to the TX and returns back to receive mode.
4. If the ACK packet is not received by the TX immediately, the data packet is sent again after a programmable delay

The following diagrams show how the packet architecture is organized:

Preamble 1 byte	Address 3-5 byte	Packet Control Field 9 bit	Payload 0 - 32 byte	CRC 1-2 byte

Table 8: An Enhanced ShockBurst™ packet with payload (0-32 bytes)

Payload length 6bit	PID 2bit	NO_ACK 1bit

Table 9: Packet control Field

1. **Preamble:** The Preamble is a bit sequence used to synchronize the receivers demodulator to the incoming bit stream.
2. **Address:** This address is the address for the receiver. It helps distinguish between nRF24L01+ if many are used which we plan on implementing.
3. **Packet Control Field:** The Packet Control Field is made up of three sections shown in table 9. It has the payload length field, a 2-bit PID field, and a 1 bit NO_ACK flag.
4. **Payload:** This section holds the data being sent from TX to RX.

5. **CRC:** The Cyclic Redundancy Check (CRC) is a mandatory error detection mechanism in the packet.

Design of the Load Controller (CAD)

Figure 14 and Figure 15 show the CAD design of the load controller box prototype that will be the product delivered to the client. This prototype box includes all the necessary elements required for the construction of the load controller. It's important to note that the main controller will have a simpler layout since it only contains the Beagle Bone Black, a 5V DC power supply and an Ethernet cable to connect to the home user router.

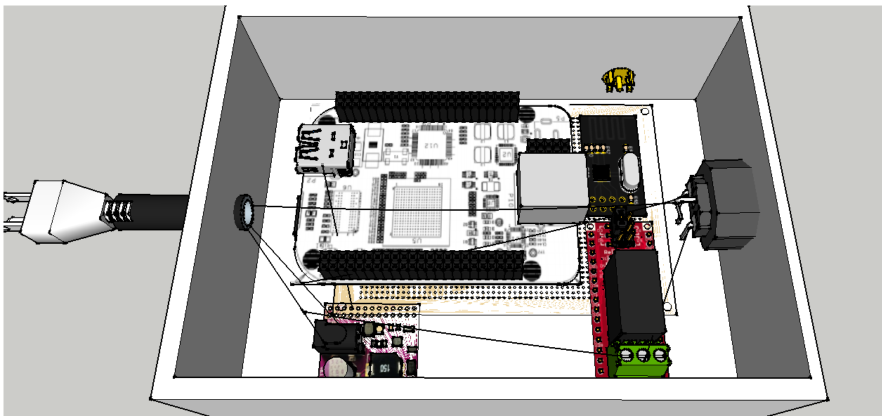


Figure 14: Displays the inside design of the Load Controller

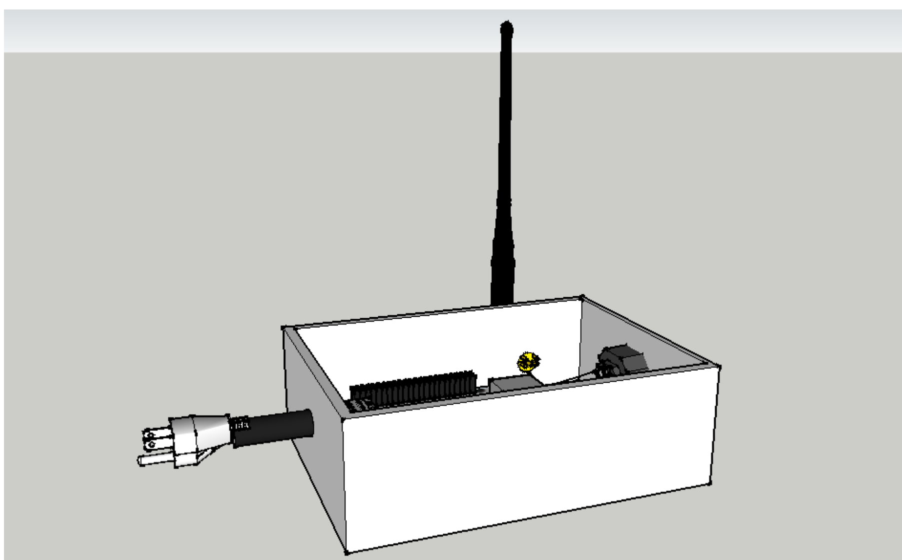


Figure 15: Displays the outside design of the Load Controller

Scheduling and Resource Allocation

Gantt Chart

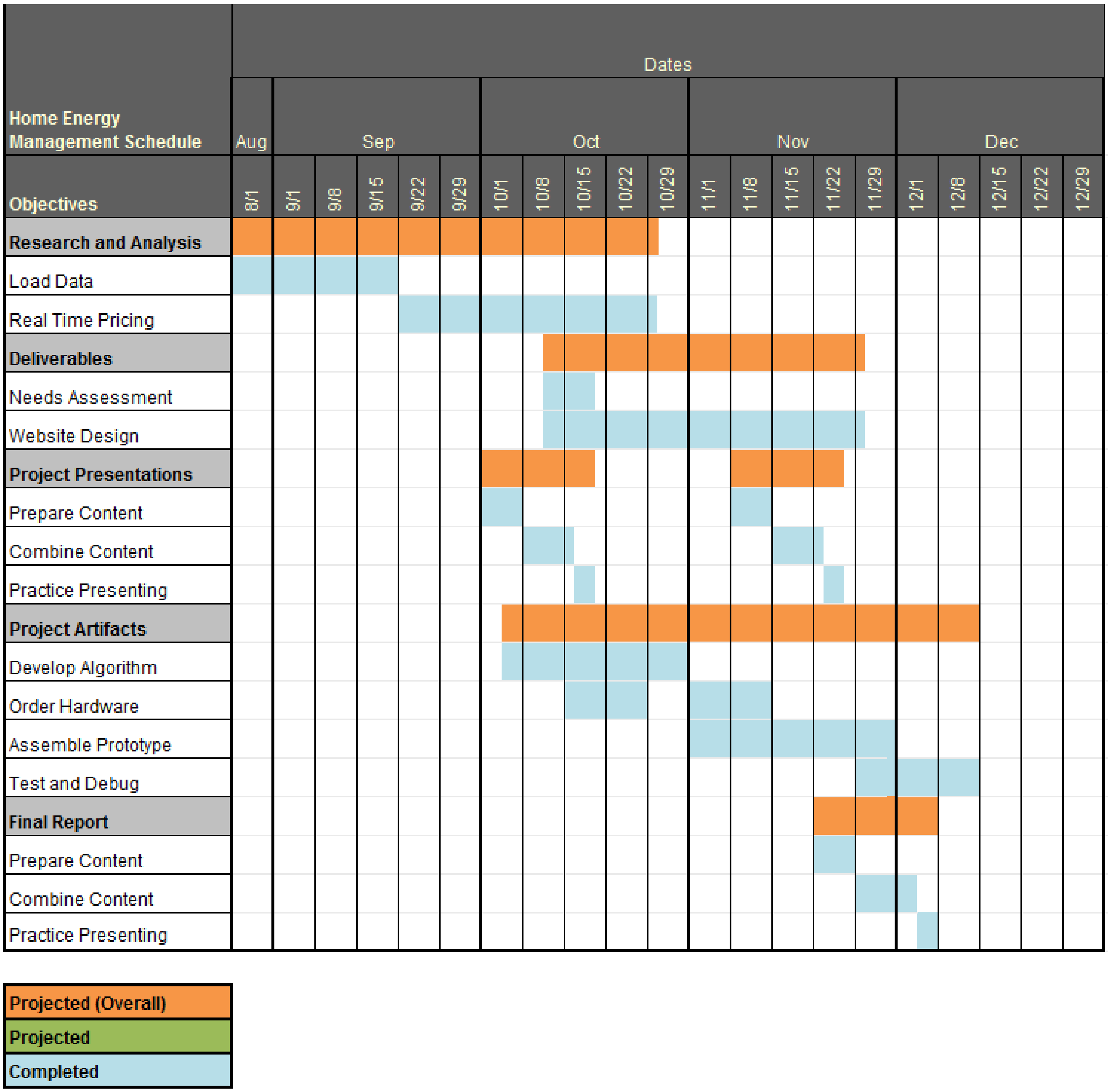


Figure 16: Displays schedule for the Fall 2015 Semester

As seen in Figure 16 above, the project is on schedule with the projected timeline. This semester was focus on the creation and design of a prototype, and next semester, Spring 2016, will focus on further development and testing of the overall design.

Projected Hours

Estimated Hours for the Spring 2015 Semester					
Weeks of the Month	Spring 2015 Semester Months				
	January	February	March	April	May
First Week	N/A	5	7	10	10
Second Week	5	5	7	10	N/A
Third Week	5	5	7	10	N/A
Fourth Week	5	5	7	10	N/A
Total Monthly (Hours)	15	20	28	40	10
				Total Semester Hours	108

Table 10: Projected Hours required for the Spring 2016 Semester

The hours of work will be distributed amongst the personnel responsible for the completion of the project. See Table 10 for an estimation of the required hours. This estimation is per team personnel, not including Dr. Omar Faruque, the Senior Design Project Advisor. Between both semesters the estimated time of completion is about 752 hours.

The personnel consists of:

Dillon Wiggins – EE – Project Manager
Ivan Remete – EE – Electrical Engineer
Pablo Aguirre – EE – Systems Engineer
Juan Ospina – CE & EE – Hardware Engineer
Michael Garcia – CE – Software Engineer
Dr. Omar Faruque – Senior Design Project Advisor

Bill of Materials/Budget

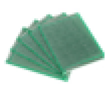
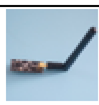
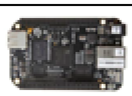
Budget Summary					
Image	Material	Vendor	Quantity	Price	Total
	MSP-EXP432P401R	TI	8	$12.99	$103.92
	Extension Cord 2ft 3-wire	Generic	3	$5.47	$16.41
	Black Universal AU Plug AC USB Power Home Travel Wall 1A Charger Adapter 1000mA	Generic	6	$3.99	$23.94
	LM74 - Temperature Sensor	TI	4	$1.84	$7.36
	5V Power Supply	Generic	1	$8.99	$8.99
	6x8cm PCBs 5pcs	Generic	1	$6.99	$6.99
	5V 1 One Channel Relay	Generic	6	$5.69	$34.14
	Nrf24l01+pa+lna: 1100m	Generic	6	$11.60	$69.60
	Beagle Bone	TI	2	$55.00	$110.00
		Budget Remaining	**$1,118.65**	TOTAL	**$381.35**

Table 11: Budget (First Purchase)

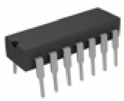
Budget Summary					
Image	**Material**	**Vendor**	**Quantity**	**Price**	**Total**
	56100C Current Sense Transformer	TI	10	$1.60	$16.00
	LM339AN - Comparator	TI	10	$0.30	$3.00
	Rocker Switch	Digikey	10	$0.66	$6.62
	10K Ohms Resistors	Digikey	50	$0.03	$1.44
	10u Capacitor	Digikey	20	$0.47	$9.40
	Push Button	Digikey	25	$0.07	$1.68
	Wi-Fi USB Adapter	Edimax	2	$9.99	$19.98
		Budget Remaining	**$1,060.53**	TOTAL	**$58.12**

Table 12: Budget (Second Purchase)

Table 11 and 12 display the overall budget for the project. The budget was initially deducted by 25% in order to have buffer room in case of any unexpected expenses. After the buffer room was made, only 25% of the remaining budget has been spent.

Results

Risks

Risks are minimal in this design project. There are two categories of risks, one is during the prototyping stage and the other is during the use of the design. During the prototyping stage, the risks that factor in are that of low voltage (120 VAC) electrical shock and burns caused by the soldering iron. The risks that come with the use of the finalized design, and the actual use of the design project, is the security associated with the design. Since the design will not have any added security, the design project is vulnerable to hacking.

Testing Procedures

One of the first tests to be completed will be the communication between the main controller and load controllers. Communication has been established utilizing the NRF24L01+ transceivers, but tests are still needed to determine the quality of the communication in various operating conditions. These conditions will simulate the conditions present in various households, such as communication through walls from room to room, communication from first floor to second floor, and communication from opposite corners of the average sized house. The NRF24L01+ will be tested under the various conditions at different frequencies as well as data rates. Completing this type of testing will help to determine the optimal position of the main controller and the optimal settings for the NRF24L01+ transceiver.

After the load controllers and main controller have been completed and connected, the next testing phase will be for the algorithm. Testing the algorithm will give real world data that can be used to advertise the product as well as determine if the algorithm controls energy usage effectively. This phase will consist of simulations as well as real world testing. Another phase of the algorithm testing will be a longevity test, data will be collected for at least a month long period and the energy savings will be examined. If the algorithm does not perform as desired it can easily be adjusted since it will only require updating software on the main controller.

Key Characteristics

A vital part of the project is selecting the adequate components for the design. After researching different modes of wireless communication, the final two choices were between the NRF24L01+ and the XBEE. The figures below display the differences between the two.

Comparison Table (Antenna versions)		
	NRF24L01+	XBEE (Zigbee)
Frequency Band	2.4 GHz ISM	2.4 GHz ISM
Protocol	Proprietary	IEEE 802.15.04
Range	1100[meters]	1000 [meters]
Data Rate Max.	2 Mbps	250 Kbps
Price	12.00	42.00

Table 13: Comparison between NRF24L01+ Transceiver and XBEE (Zigbee)

Table 13 displays a comparison between both modules. As seen the two main differences between them are the data rates values and the price difference. As observed, data rate is higher on the NRF24L01+ giving it an edge over the XBEE protocol if more information is needed to be transferred between devices. Similarly, the price difference between both modules could be an important factor for big projects and business scalability. These are some of the main reasons why the NRF24L01+ was used instead of the more popular XBEE (Zigbee) transceiver.

	Load Controller (NRF24L01+)	Load Controller (XBEE)
Box	$5	$5
Relays	$6	$6
Cables	$4	$4
PCB Circuits	$7	$7
MCU	$13	$13
Transceiver	$12	$42
TOTAL	$47	$77
x1000 Boxes	$47,000	$77000
Price Difference	$30,000	

Table 14: Comparison between NRF24L01+ Transceiver and XBEE (Zigbee) on a cost per load box level

Table 14 show how much the price difference between these tow modules could affect the overall production cost for a business model. As shown, the price difference could be a decisive factor for the feasibility of the final business design.

Another important thing to note is some of the limiting factors that the final design will have, which essentially refer to the amperage of the loads that the design will be controlling. Since the relay in each individual load controller can only handle up to 10A, this design is not suited to anything greater than that, for example a washing machine, oven, and central air unit. Yet, this design is only a prototype, and designed to show how by using this system the user will end up saving money on their electric bill.

Conclusion

The absence of a decent energy management system is one of the reasons the energy industry is facing generation problems and high electricity demands. As stated before, real-time pricing of energy could be a solution to the energy crisis, if the data generated by the utilities companies is managed correctly. The solution proposed on this report attempts to use the RTP information provided by the utility company in order to help stabilize the supply and demand curve presented by the energy generation. Many companies have active development of state-of-the-art technologies that aim to use the RTP information generated by the utility companies in order to have full control of consumers' energy usage.

The HEM system develops an idea, similar to the state-of-the-art technologies, that gives the user the ability to control the energy usage by implementing a user friendly web application that communicates with the system developed. The system contains a main controller optimized with an automation algorithm that allows the user to personalize his own settings and have real-time control of the loads where the system is deployed.

So, why developed something similar to what's already being implemented by some of the leading companies in the industry? The answer is simple, the HEM team not only wants to give control of the energy usage to consumers, but also wants to implement a state-of-the-art software that will allow the automation of the energy demand from the users perspective, giving them the ability to predefine their own personal settings for energy consumption allowing the automation of energy management to become a real possibility in the industry.

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