Home Energy Management

EML 4911C-Senior Design- Fall 2015

<u>Midterm I Report</u>

Sponsor: FEEDER

Foundation for Engineering Education for Distributed Energy

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Project Statement

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]

An option is for utility companies to implement Real Time Pricing (RTP) in order to regulate the load demand on their systems. This type of pricing will change at a certain frequency based on demand and generation. With all of the renewable energy sources being utilized energy is no longer produced at optimal times, RTP will help smooth the load curve and take full advantage of these resources.

With the implementation of our Home Energy Management System and the advantage of RTP provided by electric utility companies, consumers have the ability to adjust their energy usage in order to reduce their electricity bill. Commercial building will also be able to take full advantage of the system.

Design and Analysis

Design Requirements

In order to fulfill all the needs explained, the project will focus on the following requirements:

1. Control the different loads using MSP432 and nRF24L01P transceiver as the communication link.
2. The transceiver will use wireless RF/Wireless protocol in order to communicate back and forth with the main controller Beagle Bone Black.
3. An algorithm will be written 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 data from the website.
4. The use of microcontrollers and small low energy devices that will be energy efficient and low powered.
5. The Beagle Bone Black (Main Controller) will be communicating via Ethernet with the cloud in order to obtain the user input and most recent information from the utility company.
6. Algorithm must discern, using special settings given by the user, between the critical and non-critical loads.
7. The load controllers will detect when a load is in use and relay the information to the main controller.
8. An Android application and website will be developed in order to control the Beagle Bone Black controller and all the loads connected to the network.

Design Schematic

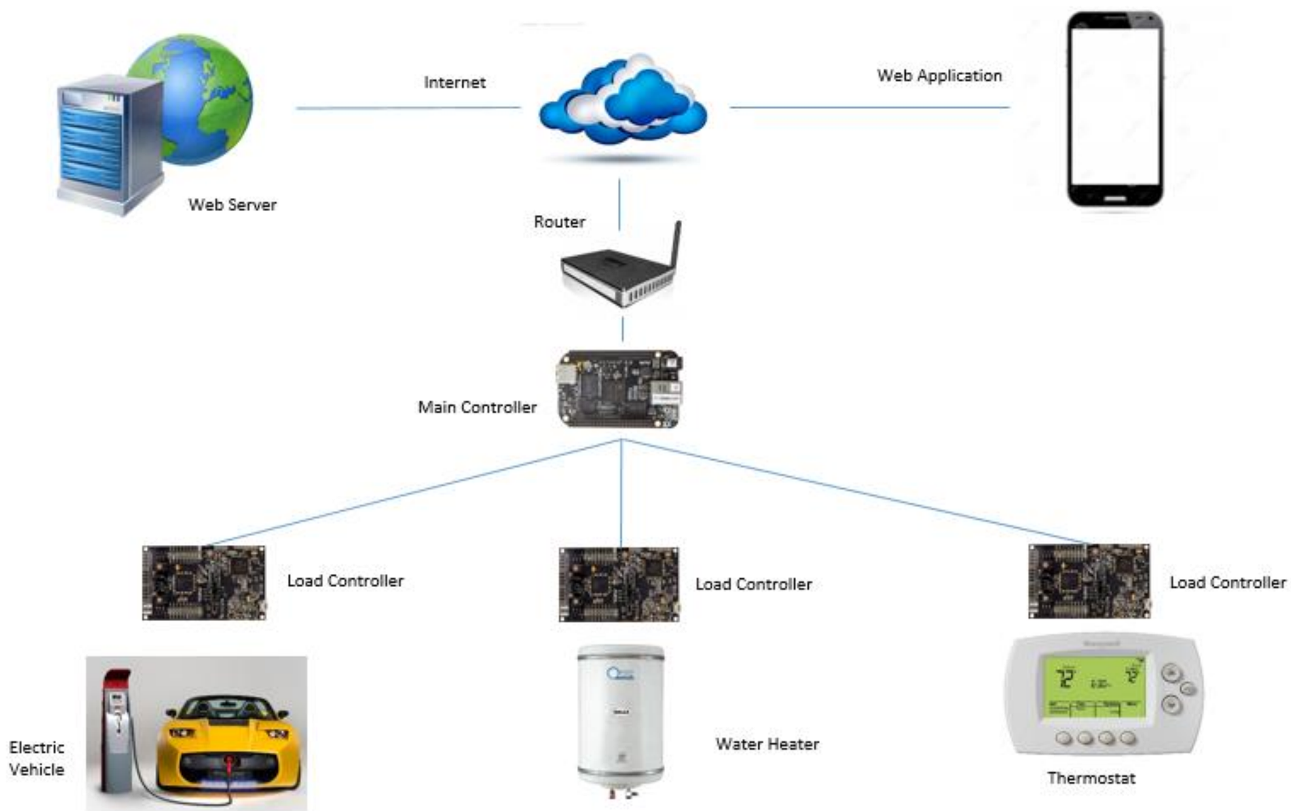


Figure 1: Displays the Top-Level Design of the Project

The concept proposed for the design of the project is presented on Figure 1. As seen, the flow of information starts at the top of the schematic, essentially in the webserver containing all the user information, pricing information and other variables that affect the algorithm performed on the main controller.

After the information is received, the main controller uses this information to decide the commands that will be sent to the load controllers according to the algorithm 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 information back to the main controller stating whether the corresponding load is on or off.

Figure 2: Displays model home with the install system

Figure 2 depicts each load including the electric car in the garage, the pool pump located next to pool, the refrigerator in the kitchen, the thermostat in the living room, and televisions in each bedroom. At the center of Figure 1 there is the main controller, strategically located to have the best signal throughout the house so each load is within reach.

Needs Analysis

According to the information obtained from the advisor/sponsor, some of the needs 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 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 have high performance controllers and reliable communication in order to have a successful deployment of the product. The other two remaining points were also taken into account when designing the project specifications but were considered as less important when deciding for a congruent 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.

Also, it's important to mention that an advantage of this design over other concepts is that this concept is designed to be easily implemented or deployed by the client with simple configurations done through the website.

Some trade-offs for the implementation of the design is the need for several main controllers when implementing the design on a large-scale environment because, even though the range of the controllers is sufficient for most cases, the main controller can only access load controllers that are on range.

Design of the Load Controller (CAD)

As seen on the project analysis, the design proposed is composed essentially of a main controller (Beagle Bone Black), load controllers (MSP432), a website for user interaction, and a server with all the information of the users. The concept for the load controller 'box' design is presented on Figure 3 and Figure 4.

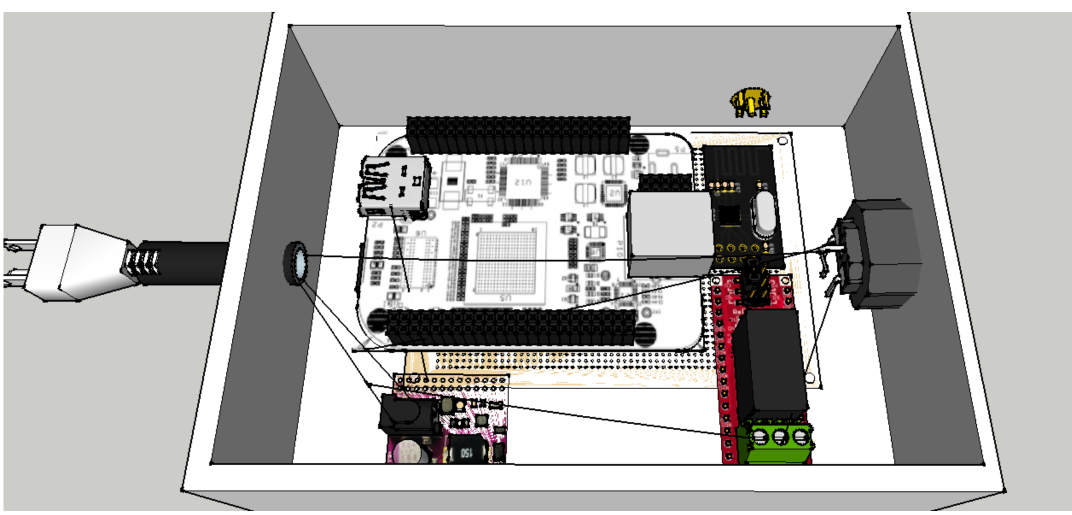


Figure 3: Load Controller Inside

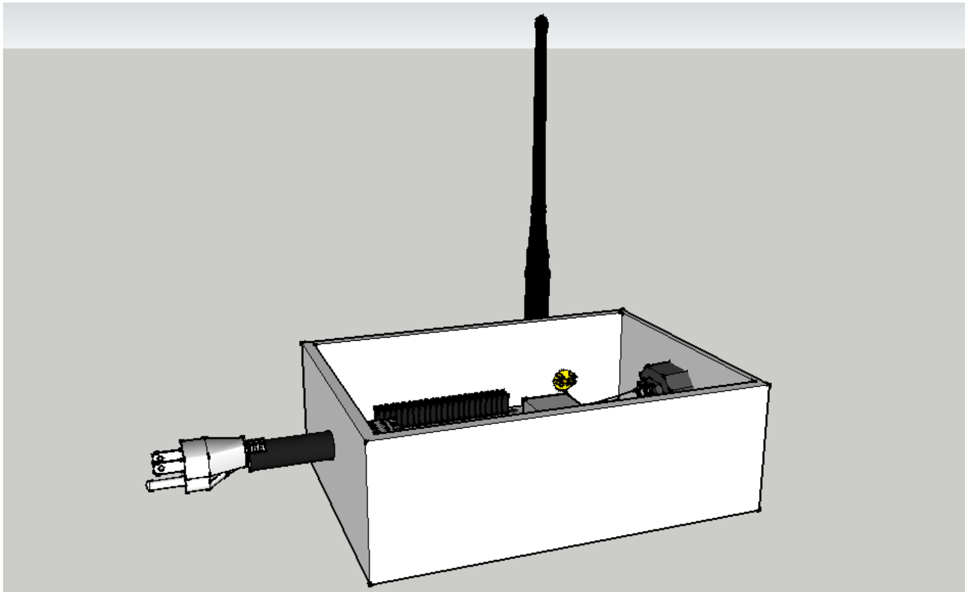


Figure 4. Load Controller Outside

On the other hand, the design for the main controller is practical design. It will only contain the Beagle Bone Black, acting as the main controller, a 5v power supply for powering the controller, and an Ethernet cable connecting the main controller to the internet via a router (the main server were the website application is hosted).

Hardware Specifications

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 (Main Controller) Specs

Figure 5. Beagle Bone Black

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: NRF24L01+ Transceiver Specs

Figure 6. NRF24L01+ Transceiver

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 4: Comparison between NRF24L01+ Transceiver and XBEE (Zigbee)

Table 4 displays the that the data rates Baud for data transfer is higher on the NRF24L01+, i.e. more data can be transferred to the loads controller per second. The price difference between both modules could be an important factor for big projects and business scalability. This is why the NRF24L01+ was used instead of the more popular XBEE (Zigbee) antenna. If the system is to be implemented on a home model, the following Table 5 displays the estimated price difference.

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

Scheduling and Resource Allocation

Gantt Chart

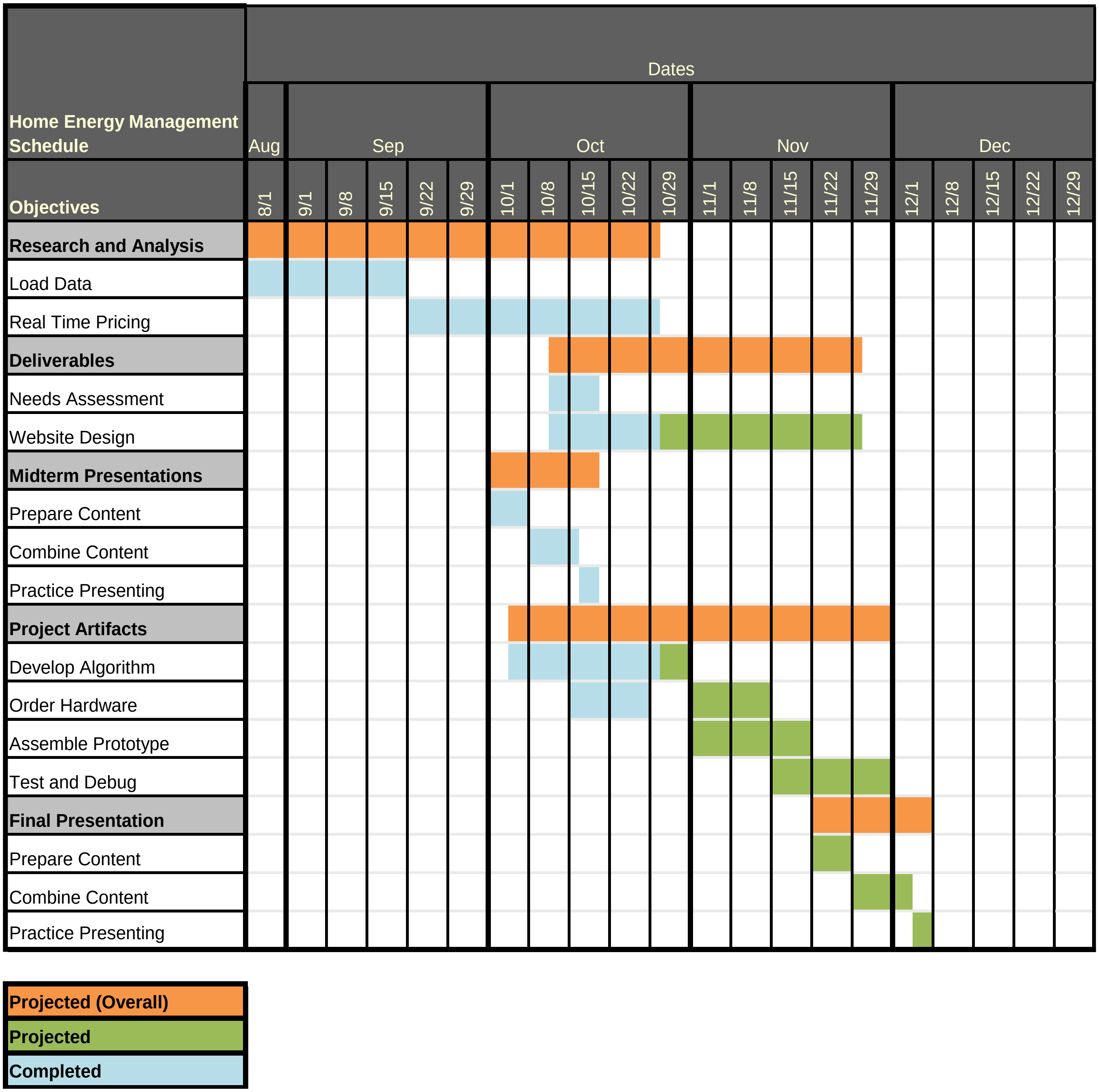


Figure 7: Displays schedule for the Fall 2015 Semester

As seen in Figure 7 above, the project is on schedule with the projected timeline. This semester is focused on creating and testing a prototype to then be able to recreate it for the Spring 2016 semester.

Projected Hours

Estimated Hours for the Fall 2015 Semester					
Weeks of the Month	Fall 2015 Semester Months				
	August	September	October	November	December
First Week	N/A	N/A	1	5	10
Second Week	N/A	N/A	5	5	10
Third Week	N/A	1	5	5	10
Fourth Week	1	2	5	5	10
Total Monthly (Hours)	1	3	16	20	40
				Total Semester Hours	80

Table 6. Projected Hours required for the Fall 2015 Semester

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 7. 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 6 and Table 7 for an estimation of the required hours. This estimation is per team personnel, not including the 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

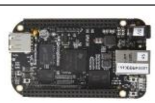
Budget Summary					
Image	**Material**	**Vendor**	**Quantity**	**Price**	**Total**
	MSP-EXP432P401R	TI	8	$12.99	$103.92
	Extension Cord 2ft 3-wire	Generic	3	$5.47	$16.41
	Black Universal AU Plug AC USB Power Home Travel Wall 1A Charger Adapter 1000mA	Generic	6	$3.99	$23.94
	LM74 - Temperature Sensor	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 8: Projected budget for the project

Table 8 displays 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 (120VAC) 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.

Validation of design/Key Characteristics

The TI-Beagle bone black (Main Controller), will be connected to the internet via Ethernet, where the user will be able to control the load controllers, by assigning the priority of the loads and over riding the state of the load (ON/OFF). The other use of the website will be the streaming of real-time pricing for the beagle-bone, where the controlling algorithm is set (since the use of real-time pricing is yet to be implemented, a projected model will be used instead). The beagle bone will be get its power from a 5V DC power converter, and will connect with the load controllers using the NRF24l01 Transceiver. The transceiver will send 2 bytes of information to the load controller using 2.4GHz ISM Radio Frequency. The transceiver uses ShockBurst for automatic packet handling and timing. [2]

The load controllers will consist of the TI-MSP432 Launchpad, which will take care of communicating with the beagle bone, and determining the state of the output (ON/OFF) as well as remotely switching the load based on the algorithm and the relay. The Load controller will be connected to the wall socket (110-120VAC) where the neutral and hot wire will then be spliced and connected to a 5V-1A dc power supply. The power supply will power the MSP32, the transceiver, and the relay. The relay handles 120-240VAC up to 10A.

One limiting factor to which the final design will have is 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

After many different design drafts and ideas, the final design will best incorporate the requirements and budget for the customer as well as providing a durable, mobile, and easy to use product for any population. The design that the team chose includes a main controller, a web server, load controllers, a mobile app, and an algorithm. A single BeagleBone Black will act as the main controller that controls what loads need managing by constantly retrieving data from the webserver and computing the algorithm. Each Load Box will have an MSP432P401R that receives the information from the main controller and controls the loads energy usage. These load boxes are mobile when replacing or adding loads to the home. The already developed Load Boxes can be added or removed from the system by using the website. The website will have an option that allows the user to add a load in, as well as describe its functionality and settings so that our algorithm can best be utilized. The web server will host the real-time pricing information from a utilities company and a user interface that allows full control of the project for the user. The app will allow the user to remotely control the system from any location. Overall, the Home Energy Management system solves all of the requirements set out by the customer, stays within budget with overhead for future costs, and minimizes all possible risks as well as possible.

Smart appliances will not need the Home Energy Management System because smart appliances have specific algorithms that interface with the user and minimizes its energy usage. To incorporate these into the Home Energy Management System, simply not adding a load box between the load and its respective power socket will have the load seem invisible to the algorithm and system.

Power-line communication carries data through the AC electric power transmission by using a high frequency bandwidth. This system could be used in this project but it requires more hardware while the NRF24L01 transceiver has much less hardware and is easier to use.

References

[1] U.S. Department of Energy, "BENEFITS OF DEMAND RESPONSE IN ELECTRICITY MARKETS AND RECOMMENDATIONS FOR ACHIEVING THEM," February 2006. [Online]. Available: http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_Benefits_of_Demand_Response_in_Electricity_Markets_and_Recommendations_for_Achieving_Them_Report_to_Congress.pdf.

[2] Nordic Semiconductor Revision 1.0 Page 27 NRF24L01+ Product Specification