Department of Electrical and Computer Engineering

Howard University

EECE 404: Senior Design II

Fault Location by Smart Meter

Final Report

By

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Date Assigned: 04/18/12 Date Submitted: 04/25/12

We certify that this is an accurate Final Report and we are in agreement that this report is an accurate representation of the project.

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Name (Print) Signature Date

I certify that this report is an accurate representation of the project and I approve it.

____ 04/25/2012

Advisor (Print) Signature Date

Acknowledgements

Dr. Charles Kim

Mr. Tom Bialek (San Diego Gas & Electric)

Clarence Bell (Federal Energy Regulatory Commission)

Eric Borden (Pepco)

Senior Design Class

Executive Summary

The focus of our project was to create an algorithm to utilize the "last gasp" or help signal sent from smart meters to minimize the area utilities have to search for a fault in real-time on a distribution circuit. The last gasp signal contains information on the id number of the smart meter as well as the power status of the load the smart meter is connected to. As a group we researched different methods of using this information to accomplish our main goal and ended with utilizing Google Maps as a visual display for the output of the algorithm. For actual implementation we utilized the Arduino Uno R3, Arduino Wireless SD Shield, Zigbee Series 1 Modules, and Google Maps Application Programming Interface. According to our design requirements we were successful in creating our algorithm.

Table of Contents

1. Background

The objective of our senior design project is to develop and implement a method of fault location utilizing smart meter technology. Our goal was to have a physical prototype in order to display how the area in which utilities will have to search for a fault on an electric power distribution circuit can be minimized through the last gasp or help signals that smart meters can send. Smart meters have the ability to wirelessly transmit and receive information. Examples of information that can be transmitted are the power consumption of the load it is electrically connected to, the bill information of that load, and much more. The most valuable information we need to implement our project is the alert, or "last gasp", signal that the load the smart meter is connected to is about to or has lost power. By using this data we created an algorithm that can locate a fault by pinpointing which smart meters indicate they are still operational versus those that are not operational. Our final algorithm was able to do this successfully utilizing Google Maps and the application programming interface associated with it.

2. Problem Formulation

Utility companies rely primarily on phone calls from customers to alert them of faults in the power distribution networks. Once enough calls have been received to estimate the location, a crew is sent to manually locate and repair the fault. There are several problems with this current approach that lead to the need to develop a new fault location algorithm. Customers often do not call utilities, or they may be at work and unaware of the outage until the evening. Thus, utilities are provided with very little information necessary to locate the fault. This causes lengthy power outages, unhappy customers, lost profits and potentially damage to the power system.

It is necessary to design a new fault location algorithm utilizing the availability of smart meters. The system must be able to automatically find the GPS coordinate of faults based on "last gasp" data sent by the smart meters. Once the coordinates are located, the address is located on a map and provided to repair crews. This entire process must be completed in no more than 5 minutes, and the location identified must be accurate to within four city block.

3. Current Status of Art

In this current day in age, the fault detection method is simple, yet very tedious. As of right now to even know when a fault has occurred, we have to wait for a customer to report that their power is out. Depending on the severity of the situation, dictates when crews are sent out to that respected fault line. Once crews arrive to the fault line, they then have to start at the beginning of the fault and travel along the entire line until we reach the fault. The only problem with this is that a single fault can stretch over counties at a time. Once the fault is reached, we must go over the rest of the line to ensure that there are no other faults on the line. Once this is done, we then report back to the customer to let them know that the fault is fixed and to see if the electricity is back on.

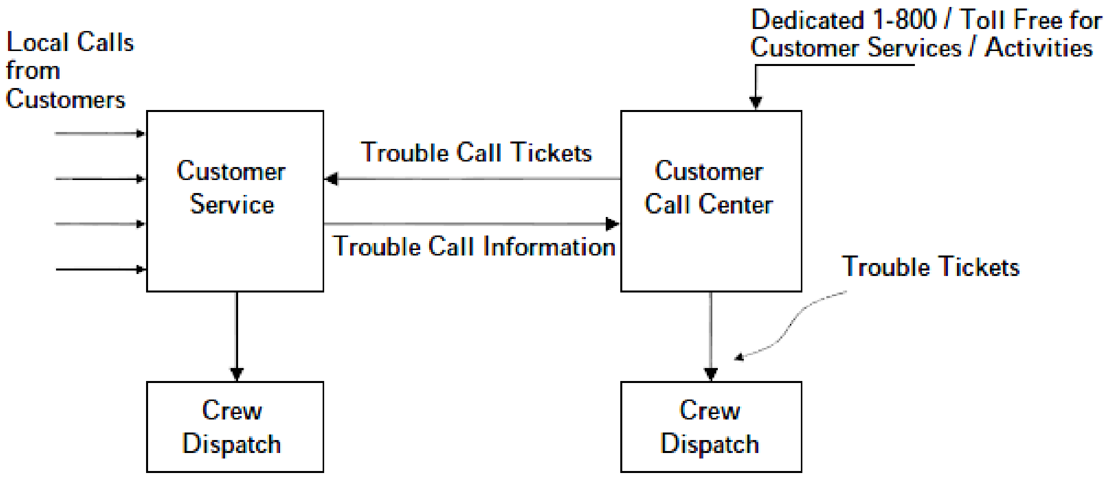


FIGURE 5.1
Trouble-call-handling sequence.

From source [4]: Example of current status of fault detection through trouble calls

This process is very tedious and time consuming and any given scenario can impact searching for a fault such as, if there are two different faults. If there happens to be two different faults you spend twice as long on the power line because you do not know that there are two different faults. The same goes for if there are two different locations without power, such as if an entire neighborhood goes out, so on and so forth. The list of different scenarios is great, so there needs to be a more effective way in detecting faults that is more time effective and more dependable.

4. Design Requirements

- Be able to locate the area of a fault in 4 minutes maximum
- Locate area accurately within 2 city block radius
- Utilize IEEE standard 802.15.4 in implementation of design

The IEEE 802.15.4 standard specifies physical layer and media access control for low-rate wireless personal area networks. It is the basis for Zigbee, ISA100.11a, WirelessHART, and MiWi specifications, each of which further extends the standard by developing the upper layers which are not defined by 802.15.4.

5. Solution Generation and Selection of Top Design

Smart meter technology is becoming a commonplace in many distribution networks, and these meters are capable of collecting large quantities of data about the loads. Presently, much of this data is going unused. However, this solution demonstrates a process that can use the data collected by smart meters to minimize the area the utilities must search in order to locate faults in a distribution network. Implementing this design will significantly reduce the time that workers spend locating faults and the time customers are without power. Consequently, utilities will increase profits by reducing the cost of physical labor and minimizing the time that they are unable to sell power.

Among the many capabilities of smart meters is to generate a “last gasp” signal as they are losing power. Using the ANSI C12.22 protocol for data communication networks, the meter is able to send this signal to the control center. During a power outage the control center collects the last gasp signals of all the affected smart meters and maintains a database containing the state of every meter. Compared to the present technique of waiting for customers’ calls, this approach quickly generates a complete picture of the affected area. The control center uses this data to produce a map of the distribution system highlight the outage area and the probable location of the fault. This map is delivered to maintenance crews to aid them in expediently locating the fault.

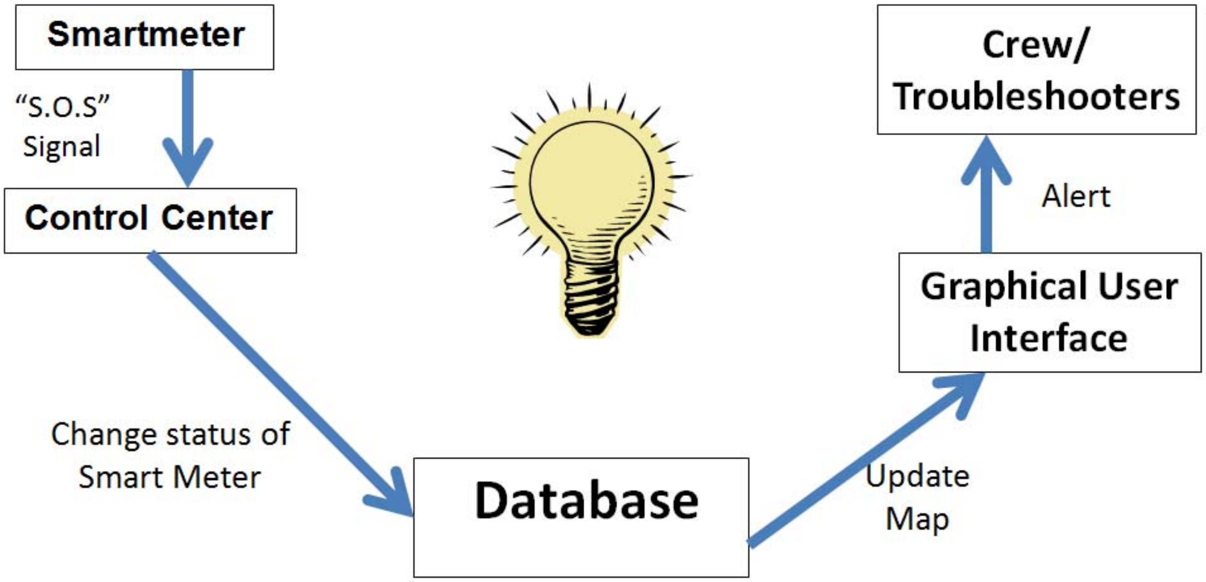


Image. Illustration of system to locate fault using last gasp signals.

In selecting our top design, we took two similar systems into consideration. Our first design approach collects last gasp signals at the control center, and uses the data to create an approximate location of the fault. A graphical user interface (GUI) including a map of the outage area and fault location is generated. Each repair crew has a laptop which is update in real time by the control center to provide workmen with the same information that is seen in the control center. This solution allows for the fastest and most accurate delivery of information to repair crews, but requires that every crew has a laptop and access to the Internet.

Our second design calculates the location of faults in the same manner. However, rather than send the information directly to crews’ computers, the information is relayed along my employees in the control center. When employees in the control center calculate the location of a fault, they must call repair crews and provide them with an address. The benefit of this approach is that it is not necessary for every crew to carry a laptop and have internet access, potentially saving money and eliminating the need for Internet access.

Solution 1	Solution 2
• Smart meter sends last gasp to control center. • Within the control center the database is updated. • Information is sent crewmen's laptops and displayed using map embedded in graphical interface.	• Smart meter sends last gasp to control center. • Within control center the database is updated. • Dispatcher calls crewmen with coordinates of fault location. • Crewmen travel to location.

Comparison of two solution approaches.

From the above table, it is apparent that the two solutions are very closely related. However, because the first solution is completely automated it operates faster than solution 2, and it also increases reliability by reducing the risk of human error. Furthermore, more information is provided to crews, thus allowing for increased efficiency in locating the fault.

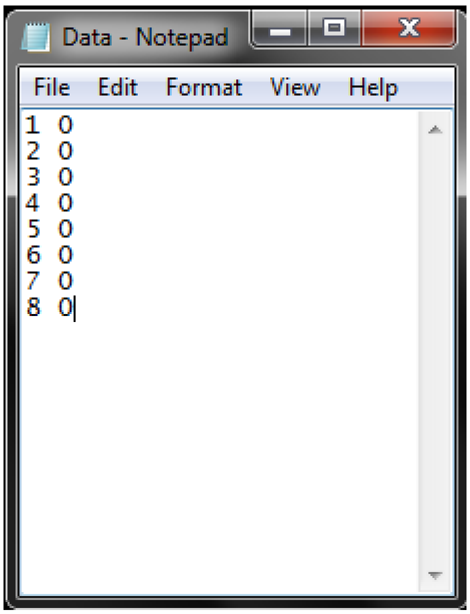
		Solution 1		Solution 2	
	Weight	Rating	Rated Score	Rating	Rated Score
Time	4	3	2.2	1	1.6
Reliability	3	3	.9	2	.5
Total score			3.1		2.1
Rank			1		2

Rating of the two solution approaches.

6. Implementation of the Top Design

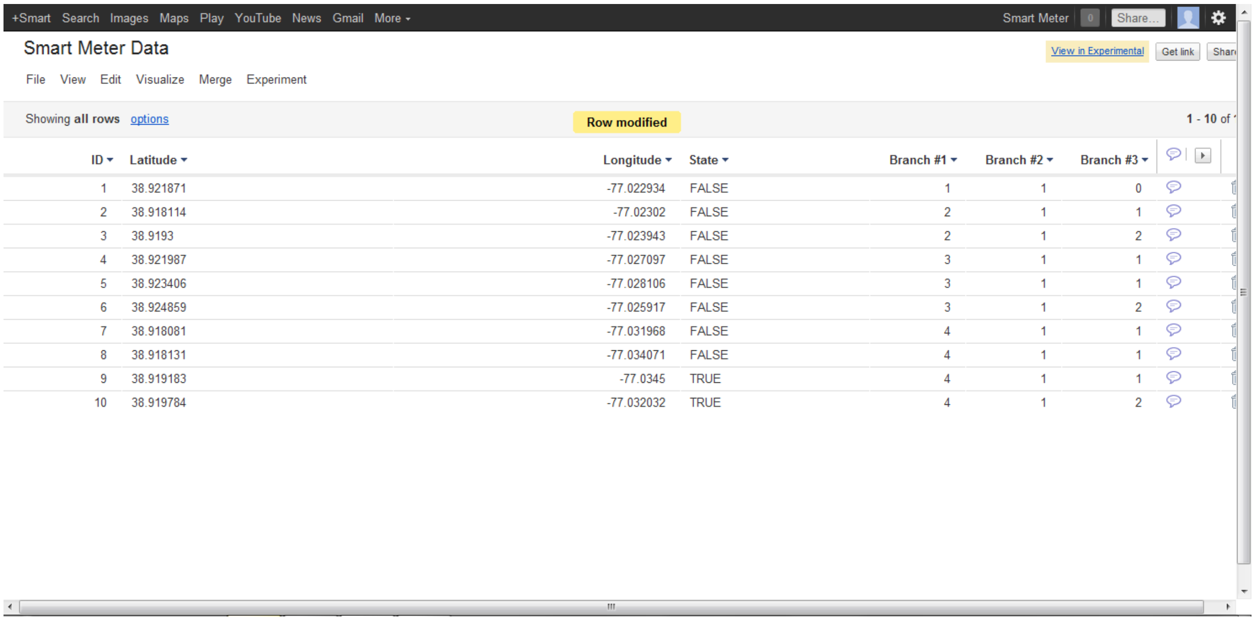
Current smart meter technology is able to communicate two ways between the meters and the control center. Thus, this design need not address smart meter communication issues, but rather produce an algorithm to locate faults and provide this information in a graphical manner. The implementation of the top design consists of 4 key features: an online Google Fusion Tables Database, JAVA code to retrieve smart meter data and update the data base, a fault location algorithm, and a GUI utilizing Google Maps.

Upon receive last gasp signals, the receiver initially stores data as a text file on the base computer. A JAVA program running in the back ground is then responsible for reading data from the text file and updating the Google Fusion Tables online. In order for this process to occur data must be stored in the text file using a very specific format. The first number in each line represents the id number of the corresponding smart meter. This number is followed by a space and then either a 0 or 1; 0 representing a loss of power and 1 representing restoration.



Sample received smart meter data, when meters 1-8 lose power.

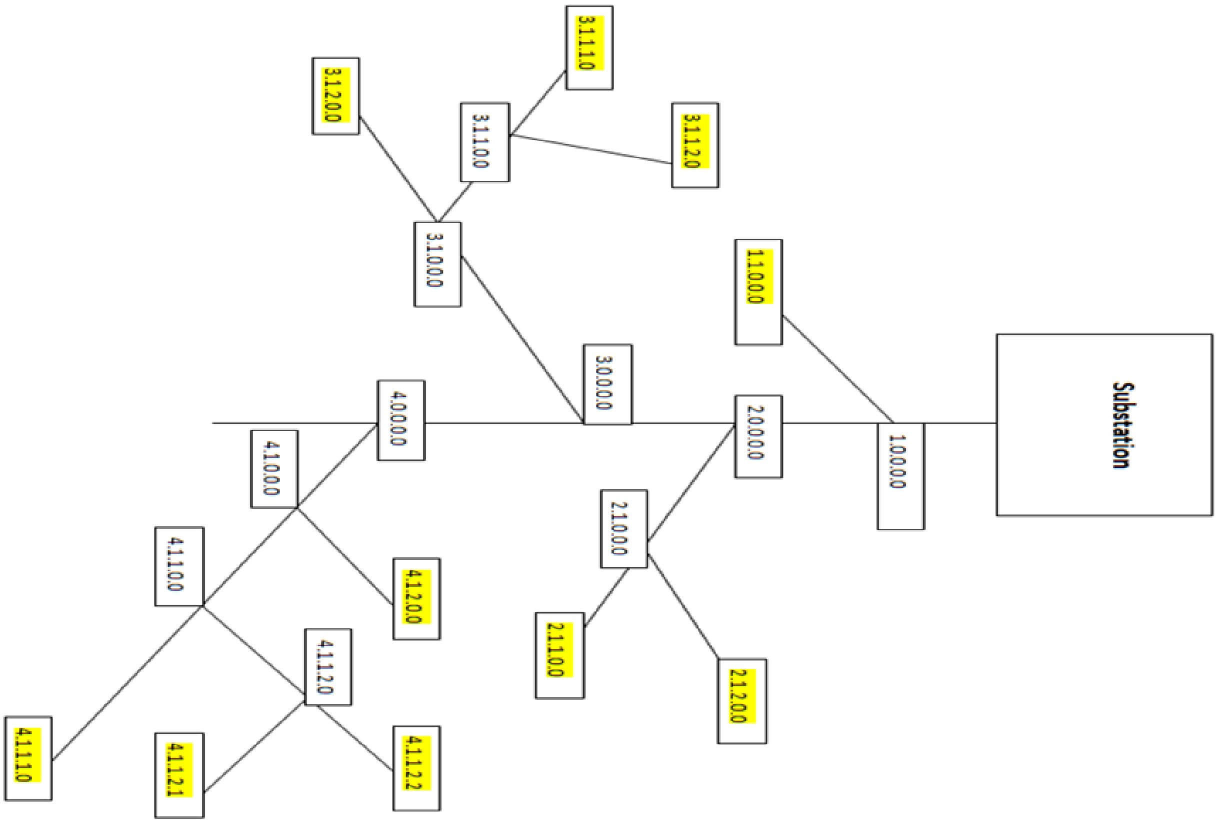
Google Fusion Tables are responsible for maintaining a complete profile of every meter in the distribution network. The following information is stored about every meter: ID Number, Latitude, Longitude, State, and the branches leading to the meter.



ID	Latitude	Longitude	State	Branch #1	Branch #2	Branch #3
1	38.921871	-77.022934	FALSE	1	1	0
2	38.918114	-77.02302	FALSE	2	1	1
3	38.9193	-77.023943	FALSE	2	1	2
4	38.921987	-77.027097	FALSE	3	1	1
5	38.923406	-77.028106	FALSE	3	1	1
6	38.924859	-77.025917	FALSE	3	1	2
7	38.918081	-77.031968	FALSE	4	1	1
8	38.918131	-77.034071	FALSE	4	1	1
9	38.919183	-77.0345	TRUE	4	1	1
10	38.919784	-77.032032	TRUE	4	1	2

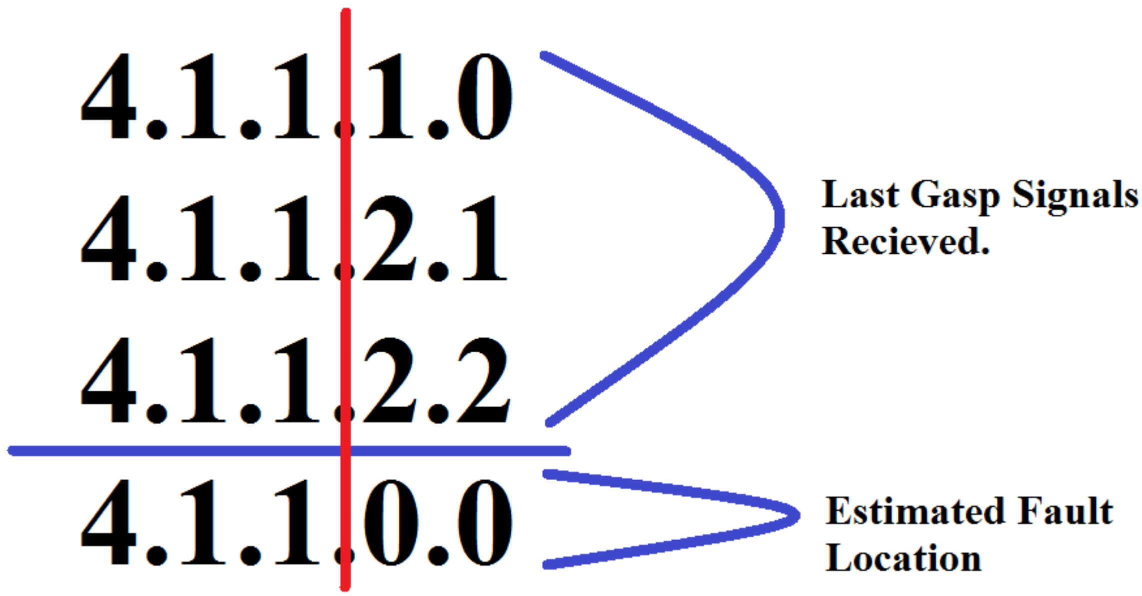
Fusion Table after meters 1-8 lose power.

The single most important piece of the final design implementation is the algorithm used to locate faults. This algorithm relies on a unique way of addressing all of the smart meters and branch points in the distribution network. In addition to a physical address, each smart meter can be located on the network based on its branches and sub-braches. The first branch corresponds to the first number in this “branch address”, the first sub-branch to the second number and so forth. The first step to locating a fault is to create an additional map of the entire network by assigning each smart meter a “branch address” in this fashion. Smart meters are represented by the highlighted boxes, and branch points by the non-highlighted ones.



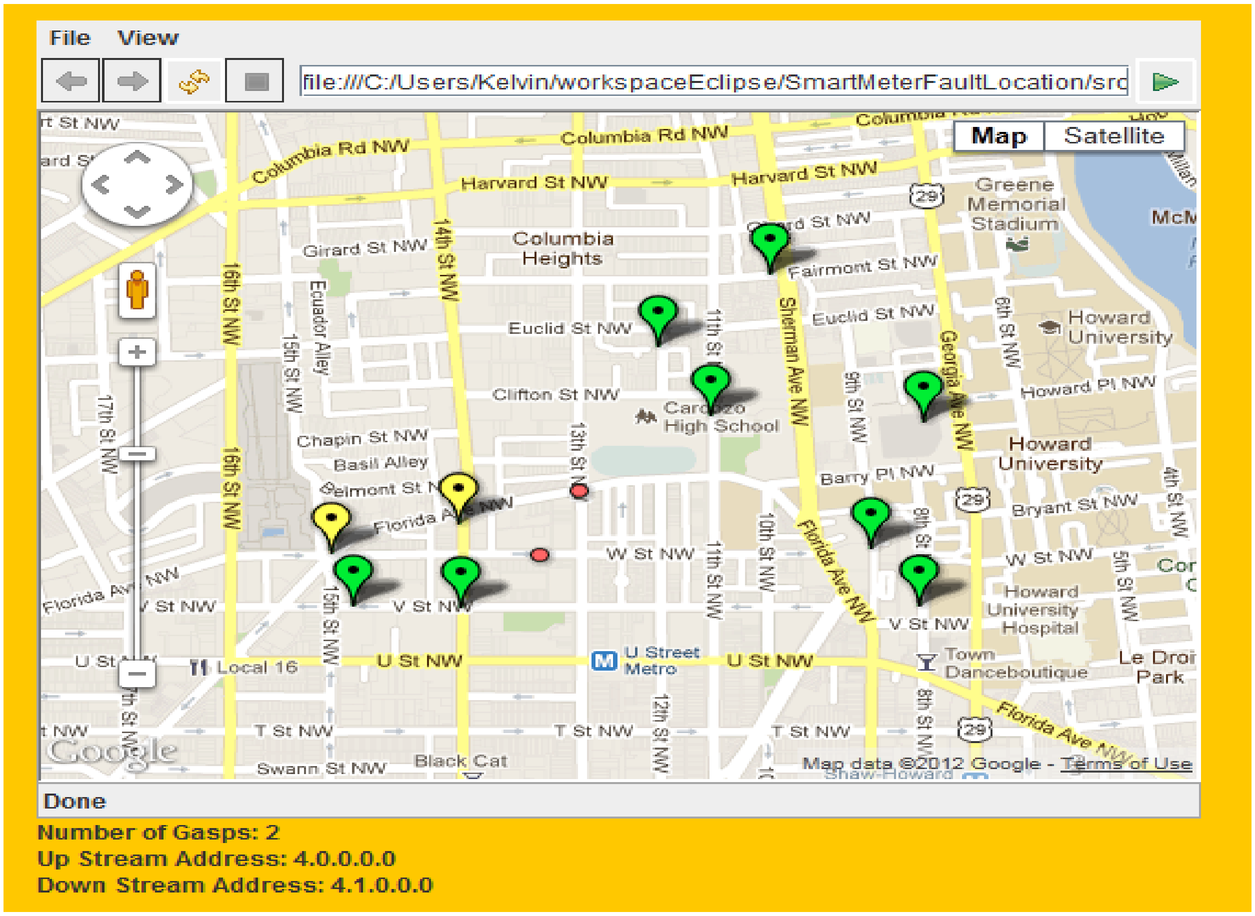
Map of smart meter "branch addresses."

When the control center recieves last gasp signals, an index of all the corresponding "branch addresses" is compiled. The first branch numbers of all the addresses are compared to one another, the the second branch numbers and so on until they no longer all match. At this point a single address is created corresponding of all the values that matched, and then zeros are used to fill in the remaining branches. The resulting address can be converted back into a lattitude and longitude, and it is the approximate location of the fault.



Calculation of fault location estimation.

The final step of this implementation is creating a GUI to display the network data. Like the other components of this project, this was implemented using JAVA, so that it is portable and will run on any device that the work crews have. The basic interface is created by embedding a web browser in a JAVA frame. This allows a Google Map to diplay all of the smart meters and the approximate location of the fault. In addition to the graphical display, the number of dead meters as well as the estimated fault location is diplayed as a text. Live meters and dead meters are represented by green and yellow meters respectively, and approximate fault locations are represented by red dots.



Example map displaying network information.

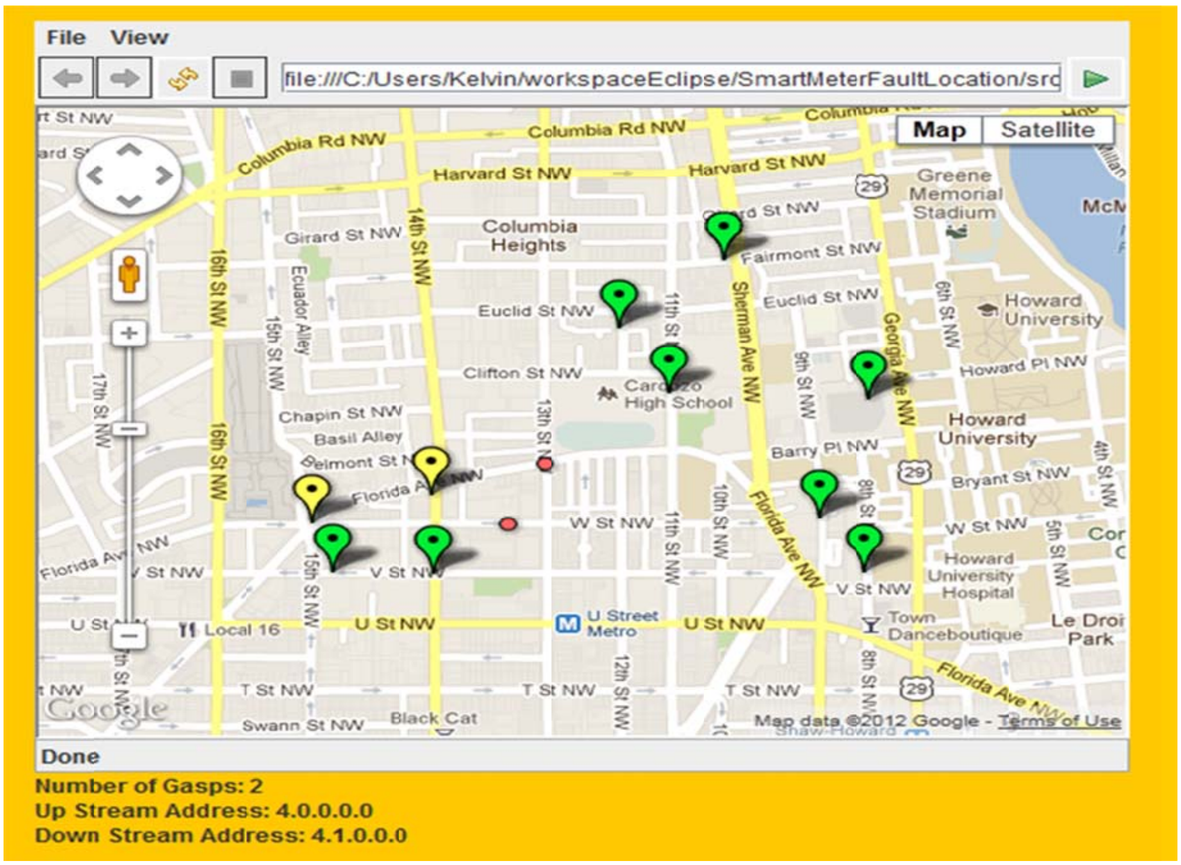
7. Performance Analysis and Evaluation

Evaluation Plan

The project was tested using three zigbee transceiver modules coupled with Arduino Uno boards to represent smart meter detection and their functionality. The receivers were to send their current status to a computer text file, which would then update our database, represented by the Google fusion table, and print out the status on a Google map. This tested the speed of the response and also the accuracy for where we thought the fault was located. The map was created based on our algorithm to locate our fault.

Algorithm

The algorithm states that each smart meter and branch is labeled by number. As the load a smart meter is connected to loses power, it will change the very last number in the ID number to zero and send it to the control center. Based on the number that starts the ID, we are accurately able to locate which branch the smart meter is located. Crews will then go out to that respected branch and fix the fault.



The map, which was previously shown earlier in the report, displays the location of the power outages indicated by a yellow dot and gives a rough estimate of where we believe the fault is which is indicated by the red dots. Crews or troubleshooters will then go out to these areas and search these respected lines to find the fault.

Our project was tested in an open area. The results were measured against the initial design requirements.

•Locate area of fault within four minutes

Result: The system is able to send the signal to central control center and give a rough estimate on where the fault is believed to occur anywhere between almost immediately to 2 mintues

• Minimize location to a four block radius

Result: Based on the algorithm, the google map gives a estimation of where the fault occurred within a 2 block radius.

8. Conclusion

The time it takes for the faults to be located will drastically decrease. No longer will crews have to wait for a homeowner to call and say the power is out and go out, searching the entire line. Even though the algorithm needs to be changed for more complex maps we believe that this would be very successful in the future. Sending a wireless signal will make the time it takes decrease substantially. We believe our algorithm will be very successful. In executing the project our timeline included simulation and testing and building the actual smart meter prototype. We are definitely able to receive signals and output the result to Google maps and give a estimation point on where the fault is located. Facilities Utilized were three Zigbee chips equipped with boards, Eclipse, Google Maps, Google Fusion Tables, and extensive knowledge in Java. The total Design implementation cost $281 and we would like to thank Dr. Kim and Tom Bialek from San Diego Gas and Electric for assisting and advising us with our project.

9. Recommendations

Recommendations on the project include making the algorithm efficient on more complex distribution circuits. Also, creating more methods of visually displaying the fault location information, such as creating a mobile application for smart phones and Iphones would assist in the fast growth of technology. Another important recommendation is to make it so the area of the fault can be located as well as identify the possible type of fault, which could in turn make the transition of fixing the problem faster and easier, and prevent damage, if any, to the system.

10. References

[1] L. Keranen. *Usefulness of AMR Data in the Network Operation.* Masters of science thesis, Tampere University of Technology, Tampere, Finland. 2009. Retrieved [Dec. 8, 2011].

[2] K. Salant. (2010). *Smart-grid technology gets electric utilities and consumers interconnected.* The Washington Post. Internet: http://www.washingtonpost.com/realestate/smart-grid-technology-gets-electric-utilities-and-consumers interconnected/2011/05/23/AGNf2wOH_story.html, 2010. [Nov. 11, 2011].

[3] Schweitzer Engineering Laboratories. (2011). Fault Indicators and Detectors. Internet: http://www.selinc.com/FCI/FaultIndicatorsandSensors/, 2011. [Nov. 12, 2011].

[4] J.A. Momoh. *Electric Power Distribution, Automation, Protection, And Control.* Boca Raton, FL: CRC Press Taylor & Francis Group, 2008, pp. 135-37.

11. Appendices

A. Final Design Requirement

B. Final Design Proposal

C. Resumes of all team members

A. Final Design Requirement

Algorithm is able to locate the area of a fault in 4 minutes maximum
Location of fault area accurately determined within 2 city block radius
Utilize IEEE standard 802.15.4 in implementation of design
The IEEE 802.15.4 standard specifies physical layer and media access control for low-rate wireless personal area networks. It is the basis for Zigbee, ISA100.11a, WirelessHART, and MiWi specifications, each of which further extends the standard by developing the upper layers which are not defined by 802.15.4.

B. Final Proposal

Department of Electrical and Computer Engineering

Howard University

Fall 2011

Senior Design Final Proposal

Fault Location by Utilizing Smart Meters

By

Andrew Ellis

Kelvin Goodman

Kevin Peynado

12/9/2011

Advisor (Print) **Signature** **Date**

12/9/2011

Instructor (Print) **Signature** **Date**

Table of Contents

1. Introduction

The objective of our senior design project is to develop and implement a method of fault location utilizing smart meter technology. Our goal is to have a physical prototype in order to display how a fault can be located on an electric power distribution circuit by ECE day in April. Smart meters have the ability wirelessly transmit and receive information. Examples of information that can be transmitted are the power consumption of the load it is electrically connected to, the bill information of that load, and much more. The most valuable information we need to implement our project is the alert that the load the smart meter is connected to is about to or has lost power. By using this data we hope to create an algorithm that can locate a fault by pinpointing which smart meters indicate they are still operational versus those that are not operational. This proposal intends to propose the idea of fault location by utilizing the information we can obtain from smart meters that utilities can possibly use to locate faults on a distribution circuit.

2. Problem Definition

Utility companies rely primarily on phone calls from customers to alert them of faults in the power distribution networks. Once enough calls have been received to estimate the location, a crew is sent to manually locate and repair the fault. There are several problems with this current approach that lead to the need to develop a new fault location algorithm. Customers often do not call utilities, or they may be at work and unaware of the outage until the evening. Thus, utilities are provided with very little information necessary to locate the fault. This causes lengthy power outages, unhappy customers, lost profits and potentially damage to the power system.

It is necessary to design a new fault location algorithm utilizing the availability of smart meters. The system must be able to automatically find the GPS coordinate of faults based on "last gasp" data sent by the smart meters. Once the coordinates are located, the address is located on a map and provided to repair crews. This entire process must be completed in no more than 5 minutes, and the location identified must be accurate to within four city block.

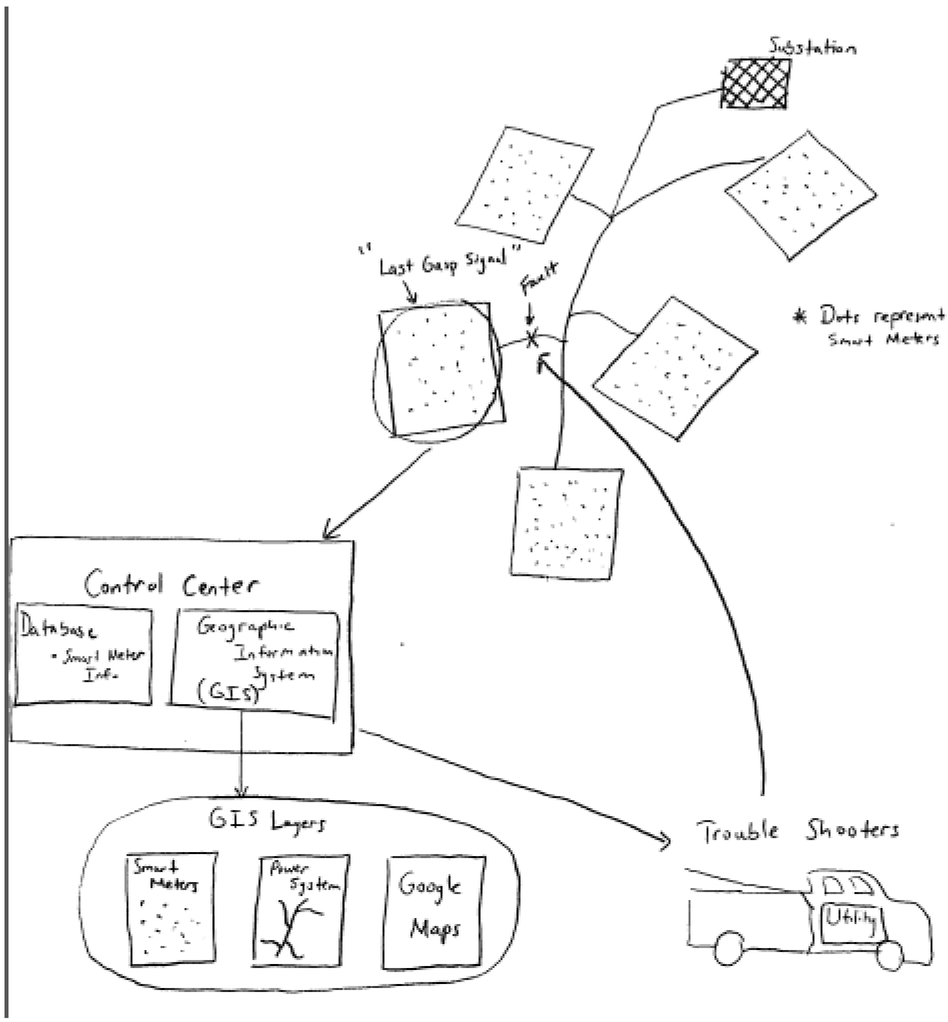
3. Current Status of the Art

In this current day in age, the fault detection method is simple, yet very tedious. As of right now to even know when a fault has occurred, we have to wait for a customer to report that their power is out. Depending on the severity of the situation, dictates when crews are sent out to that respected fault line. Once crews arrive to the fault line, they then have to start at the beginning of the fault and travel along the entire line until we reach the fault. The only problem with this is that a single fault can stretch over counties at a time. Once the fault is reached, we must go over the rest of the line to ensure that there are no other faults on the line. Once this is done, we then report back to the customer to let them know that the fault is fixed and to see if the electricity is back on.

This process is very tedious and time consuming and any given scenario can impact searching for a fault such as, if there are two different faults. If there happens to be two different faults you spend twice as long on the line because you do not know that there are two different faults at the same time because there is no way of telling other then power outages. The same goes for if there are two different locations without power, if an entire neighborhood goes out, so on and so forth. The list of different scenarios is great, so there needs to be a more effective way in detecting faults that is more time effective and more dependable.

4. Engineering Approach for Solution Generation

When a power outage occurs, smart meters in the affected area will send a “last gasp” signal containing their identification numbers to the distribution management system. A database within the management system will contain address data for all the smart meters on the grid. The address of the affected meters will be layered on top of a map of the power grid to identify the location of the fault.



The key component to our solution is the way in which smart meter addresses are stored. Because faults can occur along distribution lines, it is necessary to address smart meters based upon their location on the power line rather than their longitude and latitude. Several other algorithms define this location as a distance from the nearest substation, however several locations meters may be at the same distance from the substation, thus causing an ambiguity. Our smart meter addresses will be stored in the following format:

ID number	0123456789
Latitude	38.920455
Longitude	-77.024653

Street Address	2251 Sherman Ave NW
Neighboring meter ID 1	1111111111
Neighboring meter ID 2	2222222222
Neighboring meter ID 3(if existing)	3333333333

This format will allow us to first plot the longitude and latitude location of each smart meter, and then fill in the power lines connecting one meter to the next. This format simplifies the process of determining between which meters a fault occurred, and the possible power line that it could have occurred on. After, this is determined, the address of nearby smart meters will be sent to repair crews so that they can find the precise location of the fault.

5. Tasks and Deliverables

November

- Revise solution for locating faults by utilizing smart meters
- Meet with individuals from industry that have experience with standards/regulations, smart meters, or anything else that can assist with the successful completion of this project

December

- Familiarize selves with Standards and Regulations of NERC and FERC with regards to gathering information from electric grid technologies (smart meter)
- Familiarize and implement PSSE, Power World, or PSAT leading to indication of fault by smart meter
- Algorithm and method for model prototype

January

- Begin implementation of solution

January/ February

- Continue construction of project

February/ March

- Completing construction of project by March 21st, 2012
- Begin practicing presentation
- Make any minor changes to project

March

- From March 21st until ECE day practice presentation

6. Project Management

Group Work

- Familiarize selves with Standards and Regulations of NERC and FERC with regards to gathering information from electric grid technologies (smart meter)
- Familiarize and implement PSSE, Power World, or PSAT leading to indication of fault by smart meter
- Algorithm and method for model prototype

Kevin Peynado

- Research General Electric as it pertains to fault location
- Implement algorithm into a VHDL code to work with

Kelvin Goodman

- Research Honeywell Technologies as it pertains to fault location
- Look up any other software or distribution fault locator technology

Andrew Ellis

- Look up Schweitzer Engineering (Fault Indicator) and inquire about getting sponsorship
- Stay in contact with Clarence Bell
    - May be able to provide contact/possible advisor for our group

7. Conclusions

Overall, we propose to design and implement an algorithm to locate a fault in an electric distribution system by utilizing smart meters. The main aspects needed are the “last gasp” information from the smart meter when the load they are connected to is about to lose power.

Our engineering solution consists of taking the “last gasp” signal information from the smart meter and immediately matching the smart meters ID number with its physical address on the electric distribution system. Afterward the computer systems of the distribution management system will use the algorithm proposed in our solution approach in order to pinpoint the location of each non-powered smart meter on a geographical map. The computer system will then determine the location of the fault.

At this point we will begin implementing this design in early January, or the middle of January at the latest. Over the break we will continue to look for sponsorship for our project, preferable a utility that would be interested in our algorithm, and make amendments to our design so that we can begin implementation when we return from the break.

8. References

[1] Keranen, Laura. (2009). *Usefulness of AMR Data in the Network Operation.* Masters of science thesis, Tampere University of Technology, Tampere, Finland. Retrieved December 8, 2011.

[2] Salant, Katherine. (2010). *Smart-grid technology gets electric utilities and consumers interconnected.* The Washington Post. Retrieved from http://www.washingtonpost.com/realestate/smart-grid-technology-gets-electric-utilities-and-consumers-interconnected/2011/05/23/AGNf2wOH_story.html

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