Ubiquitous (CB)RN(E) Sensor Network for TASC, Inc.

February 11, 2014

OR699/SYST699 Capstone Project Proposal

Kyle Grunden
Gina Guerra
William Leonard

Table of Contents

Table of Figures

Abstract

As time goes on, our world continues to become more networked and more advanced sensors become part of the devices we use daily. Our cell phones, watches, and cars will soon be able to connect regularly with one another, creating a ubiquitous network of communication. This network can be used in a variety of ways. One such application that we will discuss in this paper is the detection and surveillance of Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) materials out of regulatory control. These detections are crucial for safeguarding the nation from weapons of mass destruction. Ubiquitous sensors can be used to detect some of these materials. By communicating detections in time and location, illicit materials can be localized, tracked, and ultimately interdicted.

This project is being sponsored by TASC, Inc. with the purpose of introducing a framework and analysis for the detection of CBRNE materials through ubiquitous sensor networks.

Intro

The Sponsor

TASC, Inc. is a provider of systems engineering resulting in scientific, engineering, and technical services to federal, state, and local government agencies, as well as the military. Our sponsor, TASC, Inc., based out of Lorton, Virginia, is working to solve many of the most pressing national security and public safety challenges facing our nation and the world. In terms of defense, TASC, Inc. plays a key role in supporting the protections which prevent illicit agents from entering the United States. TASC, Inc. has requested a prototype of an architecture and framework, along with an analysis of implementation for a ubiquitous network of CBRNE sensors in an everyday setting that can be continued and carried out by company computational scientists within a classified setting once more advanced sensor technologies exist.

History of Security Concerns

The United States' susceptibility to a CBRNE attack has increased over the years due to prior terrorist intentions and events. From the 1990's, the Department of Defense acknowledged both the creation of a growing number of CBRNE weapons of mass destruction and their impact on the United States. Since the terrorist attacks of September 11, 2001 and the Anthrax incident of 2001, there has been a heightened concern that nuclear weapons and chemical and biological materials pose a grave, future threat to the citizens of the United States. The Department of Homeland Security (DHS) was created to safeguard the country against terrorism and respond to any future attacks (Creation of the Department of Homeland Security). In addition to smuggling hazardous materials into the country, there are several chemical agents that are easy to obtain and produce that can be used as weapons or explosives (Nelson, 2012). Since the fear of chemical and radioactive agents getting into the wrong hands is so concerning and because of the detrimental effects of a CBRNE event or attack, it is a goal of the United States to focus their defense and security-related research toward the detection of explosive and chemical weapons that can be used as weapons of mass destruction.

Detection of explosive or chemical devices can be difficult due to the way they are concealed. Often, they are placed in crowded areas or main areas of travel so that it is difficult to be detected within the environment (Stankovic, 2006). More recently, explosive devices have been placed in overcrowded areas of high value and high visibility. In the United States, there are many public and transportation venues that are susceptible to a CBRNE incident. Such venues consist of, but are not limited to airports, sporting events, concerts, races, and speeches. Some examples from recent decades consist of the Boston Marathon tragedy, the World Trade Center bombings, and the New York City subway plot (Chakraborty, 2013). Thus, it is extremely important to provide an appropriate sensor network framework and architecture to protect the people present at these and other similar events.

Wireless Sensor Networks

A wireless sensor network (WSN) is a collection of sensor nodes organized into a cooperative network. The sensors will communicate wirelessly and self-organize when deployed, whether in an ad-hoc manner or not (Stankovic, 2006). To support the TASC, Inc. initiative to protect the United States from a CBRNE attack in particular, our group has created a model to simulate a network of sensors that detects and tracks a nuclear/radioactive source prior to its release or detonation.

Ubiquitous refers to the idea that anyone, anywhere, at any time, can be a part of a network (Park, 2005). Ubiquitous sensor networks allow for CBRNE detectors to continuously monitor the presence of illicit materials in any venue in order to prevent an incident from occurring, and just as importantly, to provide the proper authorities a timely warning (Nelson, 2012). The use of these detectors can provide intelligence and greatly reduce the time to discovery of a CBRNE source, as well as the interdiction of a CBRNE incident. The instantaneous feedback on the conditions of a venue's environment and the localization of a source are critical for a more rapid and well-organized response. If successful, an effective WSN will enable the quick detection and localization of an illicit source (Nelson, 2012).

The characteristics of a WSN are important for its efficacy. Firstly, the network must consist of a large number of sensor nodes ranging from ten to ten thousand dispersed throughout a venue (Park, 2005). These nodes can be arranged in an ad-hoc scenario or can be part of a ubiquitous and mobile network of sensors. The density and architecture of a network greatly influences its success. The more nodes that can hone in on a CBRNE source, the greater the area of detection overlay. Second, it is important that the sensors have a way to communicate, process, and transmit data among one another in order to cooperatively summarize observations of their environmental conditions (Park, 2005). Without this communication and data fusion, a network is nothing more than thousands of individual nodes acting alone, with no common purpose to track, detect, or monitor uncertain and illicit materials. What happens with this data that is collected is just as important as communication among one other. A network can have a gateway or a sink node that connects a network of sensors to other networks and the outside world. This gateway is a central location that combines the collection of information to be analyzed (Park, 2005). Lastly, a ubiquitous sensor network is useless unless the information is dealt with appropriately. Thus, the proper authorities must be alerted of any CBRNE incident as soon as the data is analyzed. In addition to the way the networks work together, their individual characteristics are significant in CBRNE source detection as well. In the case of detecting and preventing a CBRNE incident through a ubiquitous network, sensor nodes will consist of small, low cost, low-power devices that can communicate within short distances, sense environmental data, and perform minor data processing. The reduced size and reduced cost of these advanced sensors will not only be required but crucial for an omnipresent "surveillance." The reduced size would allow for the sensors to be used in numerous locations and allow them to be easily portable. The reduced cost would allow for the sensors to be used in a wide variety of devices without an increase in cost thus allowing for higher density networks.

One such sensor platform that is currently portable and used daily is the cell phone. Most cell phones have both a microphone and a camera, and can be connected to other phones via Bluetooth. Cell phones are actually part of their own network and have predictable power supplies and life expectancies. What makes them a significant entity within a large-scale ubiquitous network is the large number that exist and the vast spatial territory they encompass (Kansal, Goraczko, & Zhao, 2007). In the event that a CBRNE source is present at a public venue, cell phones that are equipped with the proper detectors can work together to collect and store location and detection data, which could be sent to a universal storage cloud. The network can localize the hazardous source and have authorities alerted. It is extremely likely that cell phones, combined with other electronic devices such as cars, watches, and cameras, can be used in unison to work together for the detection of harmful agents in the goal to protect the United States from CBRNE incidents in the near future.

Problem Statement

The Department of Homeland Security's future initiate gives hope that a successful network of CBRNE sensors will exist soon. In under a minute, when a cellular device's sensor that has been approved by its user detects volatile chemicals, it can integrate with other devices and locate the source. An alert will sound and authorities will automatically be contacted. Currently, Qualcomm, LG, Apple, and Samsung have begun research and development and they hope to produce forty prototypes within the year. (Cell-All: Super Smartphones Sniff Out Suspicious Substances).

Currently, there is a lot of literature on the capabilities of wireless sensor networks, but the focus is mainly on the topic of software configurations and modeling network performance. Existing research mostly covers technological advancements of these networks. In fact, the idea of wireless sensor networks has existed for some time now. In particular, chemical sensors are one of the most widely researched and developed sensors because they are useful in detecting improvised explosive devices, or IEDs (Stankovic, 2006). The military in particular has taken on this task. Presently, wireless sensor networks are being developed at a heightened pace; therefore, it is expected that in ten to fifteen years, ubiquitous wireless sensor networks will be common (Nelson, 2012). Thus, a preliminary architecture and procedure for the implementation and success of these networks must be developed as these networks become a reality.

In 2007, DHS published the National Preparedness Guidelines, which discussed the need to strengthen detection and response when it comes to CBRNE incidents and is interested in deploying a nationwide network of sensors to provide "real-time, early warning systems" (Nelson, 2012). Since there is quite a bit of research about WSN, but little in regards to the application of sensor networks for public safety or CBRNE detection, TASC, Inc. would like the team to elaborate on this research. Assuming a ubiquitous network of sensors is feasible, TASC, Inc. would like us to determine metrics for a comparison of the effectiveness of different networks containing varying parameters, determine any relationships existing between CBRNE source strength, network density, and sensor strength and subsequently, their impact on interdiction, and subsequently, introduce a framework for a ubiquitous sensor network that localizes a CBRNE source prior to its detonation or release.

Scope

The team will look specifically at the Macy's Thanksgiving Day Parade as the scenario for this project. The parade is a three hour event that spans 2.5 miles of New York City streets. In 2013, the parade attracted over 3.5 million people and involved approximately 8 thousand participants. In addition, over 46 million people tuned in at some point to watch the nationally televised event. Due to the sheer number of people present at the event and media attention, the Macy's Thanksgiving Day Parade has the potential for mass civilian fatalities and injuries, as well as a devastating psychological impact. The team has created a scenario in which we will look at one block at Central Park West from 75th avenue to 74th avenue, where a radioactive/nuclear source will move through the crowd on the west-side sidewalk.

Assumptions

For our scope, the team has decided to rule out topics that are not relevant to the specific goal of this project, which is to analyze the relationships between variables and metrics of wireless sensor networks. One significant assumption is that sensor implementation is feasible. The team will assume that these sensors could be implemented in order to analyze relationships between parameters of a sensor network that localizes a (CB)RN(E) source. This assumption also implies that the technology for sensors small enough to fit in a cell phone will be capable of detecting CBRNE materials in the future. This is not an unrealistic assumption. In fact, much work has already been done in this area (Cell-All: Super Smartphones Sniff Out Suspicious Substances) (Sutter, 2010).

The team assumes agnostic sensors; that is, the sensor in the network is not a specific make or model. The model assumes that there is one sensor per person. For the purpose of studying parametric relationships, the sensors' strength will remain constant for a single run or single data set of runs; varying from one set of data to the next throughout our study. In addition, the team will assume a single, agnostic source, classified by either of the following: radioactive or nuclear.

Due to the time available, we have decided that the model will only generate and track a single source. We created a preliminary algorithm to track multiple targets and gain better insight into its effects. It was concluded that multiple target tracking would add excessive time to the model creation and limit the time allotted for analysis. Simulating a single source provided the necessary data for a good understanding and analysis of the network parameters. It is to be noted that if the model generated more than one source, then multiple sources could be detected and properly tracked. However, to simulate more sources additional coding would have been required and thus exponentially expanding the required code. The biggest effect on the current model, resulting from not being able to track multiple targets, is the increased position errors when false detections are enabled. Finally, in the model, a generic source emanation function is used, which can be adjusted accordingly in order to allow a future team to conduct follow up analytics in anticipation of a particular source.

Detections by sensors will be modeled as a binary action. The source emanation will be consistent with the inverse square law. For our simulation, this emanation level will not have noise associated with it. There will be a threshold which will set off a sensor. If, at a particular range, the emanation is lower than the threshold a detection will not occur. If, at a particular range, the emanation is equal to or greater, then a detection will occur. The sensors will reset and show no detection once the emanation level decreases below the threshold level.

The variability of the source movement through the network has been limited. The source will enter the simulation area near the green square, as indicated in the diagram below, which will be fixed for all replications. It is a logical assumption for the source to enter into the area from a side street to start his movement through the simulation, as opposed to walking across the parade for example. The source will move through the simulation area either directly or with random movement, which will be discussed later. The simulation will end when the source reaches the drop off location indicated by the red square in the diagram below. We assume the source will be dropped off near the front of the sidewalk in order to cause significant damage. There are more people at the front of the sidewalk, and in addition, parade participants will be possible targets. This drop off location is fixed for all replications.

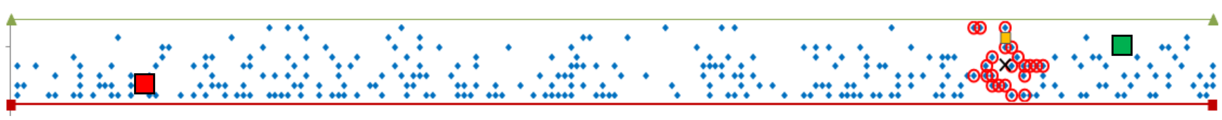


Diagram 1 - Source Path

Bandwidth and transmission speeds of the sensor network will be assumed adequate for the data requirements of the sensor networks in this study.

The team will not investigate the effects of weather on sensor detection or source emanation.

We will not be addressing the legalities of personal privacy.

Preliminary Requirements

The team has developed the following set of requirements:

1. The team shall determine, define and analyze metrics to determine the effectiveness of a sensor network
2. The team shall develop a Visual Basic model that demonstrates how a sensor network will perform in the Macy's Thanksgiving Day Parade
3. The team shall create a Quantum GIS visual to display the output of the model

4. The team shall perform modeling and analysis to determine relationships among the variables documented above
5. The team shall introduce a framework for a ubiquitous (CB)RN(E) sensor network to facilitate interdiction prior to source detonation or release

Technical Approach

Our team will create a model to simulate a sensor network in Excel Visual Basic that detects and localizes a single radioactive/nuclear source moving through an area. We will create our model from scratch with input from Allen Harvey at TASC, Inc. The model will have three main variables: density, source strength, and sensor strength. The model will be initially run with a base-case to analyze the relationships between these variables. Excursions will then be run to compile data on the efficiency of the sensor network. The model has three parts: sensor creation, source movement, and source localization.

Sensor Creation

Sensors will be generated on a grid that overlay the area of focus within the Macy's Thanksgiving Day Parade. Two sensor groups will be created: the crowd and the parade participants. Each person will have exactly one sensor.

The Grid

A grid will be used to prevent spectators from being placed on top of one another. The team will research crowd density in order to determine this grid. As for parade dimensions, our grid takes into account the outline of the parade. The vertices of the rectangular sidewalk and street area used in our model have latitude and longitude as follows:

Sidewalk Grid Area		**Street Grid Area**	
40.77816° N	73.97472° W	40.77807° N	73.97449° W
40.77815° N	73.97469° W	40.77815° N	73.97469° W
40.77763° N	73.97511° W	40.77762° N	73.97508° W
40.77762° N	73.97508° W	40.77754° N	73.97486° W

The parade starts at 77th Avenue, but viewing is not permitted until 75th Avenue, and only on the west side of the street (Macy's Thanksgiving Day Parade, 2011). The dimensions above cover the west side sidewalk along Central Park West from 75th Avenue to 74th Avenue.

Source Movement

The model will move a source through the parade grid from a designated entrance point to the point where the source is abandoned. The source will have a generic walking speed. In the base case, the source will move through the parade grid in a shortest path (least amount of steps), moving directly from the designated entry point to the source abandonment point.

Source Localization

Source Emanation and Sensor Detection

The source and each sensor will have a strength associated with it. The maximum distance that a sensor can detect a source is calculated using the Inverse Square Law from these values (Nave, 2014). The team refers to this relationship as the "see distance," which is the radius around the sensor.

Location Estimate

As the source moves through the parade area, sensor detection turns "on" and "off" as the source radius overlaps the sensor or distances itself from the sensor, respectively. For each step the source takes towards the drop off location, the model will determine an estimated position for the source.

The model will calculate an estimate of the source location by calculating the center of mass of the sensors that detect the source.

The model will include parameter inputs for the following variables that can be altered before each run: crowd density, source strength, sensor strength, minimum sensor efficiency, chance of false detection, chance for negative detection, an attenuation distance and factor, randomness of source movement, option for crowd movement, and parade movement.

Outputs

The model will output the error of actual source location and estimated source location, which includes the calculation of average error, minimum error, maximum error, the error of the distance from the source drop off location to the last estimated position when the source is seen, and the error of the distance from the last position the source is seen to the next time the source is seen. Other results that will be calculated consist of total steps, total time, percentage of time that the source is seen within the network, and average number of sensors used to localize the source.

The model will also output the locations of the crowd spectators, parade participants, source location, source estimate, false detections, and detecting sensors at each step that the source moves. The number of outputs can be altered as needed. The outputs will be in Cartesian coordinate notation, but can be converted to a latitude and longitude to create a visual of the model.

GIS Model

The GIS model will be a visualization of the team's localization results. It will aid viewers in understanding how the model works. The localization model will write an output of sensor detections, source position, and source estimation that will be plotted over a Google Maps overlay within Quantum GIS. Using the Quantum GIS experimental plug-in, Time Manager, the model will visualize and mobilize the location of the above outputs over a number of steps (or seconds) of time, creating the effect that the source, source detects, and parade are mobile. From this model, the team will create a video of this time period for visual understanding of the VBA model and base-case parameters.

Measurements

The team will define metrics in order to determine the effectiveness of the various architectures. The metrics the team will utilize are:

1. Percent of Time Source is Seen
2. Average Error When Source is Seen
3. Maximum Error When Source is Seen
4. Last Position Error
5. Maximum Location Error

These metrics will be used to compare and analyze the relationships among the many parameters in the model.

Project Plan

The project plan was constructed to enable sufficient time to meet deliverable deadlines. The project plan is detailed in the form of a Gantt chart (see figures 2 and 3 in the Appendix). The tasks are denoted by the various colored lines, and the deliverables are signified by a grey diamond. Literature review and research will take priority in the early goings of the plan and then taper off. Then, the modeling aspect will begin to take precedent; and research will be done as needed to aid model building. Once modeling is completed, analysis will begin and GIS visuals will be created. Throughout the course of the project, the team will update TASC, Inc. and George Mason University via progress reports, culminating with a final

References

Cell-All: Super Smartphones Sniff Out Suspicious Substances. (n.d.). Retrieved from Homeland Security: https://www.dhs.gov/cell-all-super-smartphones-sniff-out-suspicious-substances

Chakraborty, B. (2013, April 16). *politics*. Retrieved from foxnews: http://www.foxnews.com/politics/2013/04/16/use-ieds-in-us-terror-attacks-on-rise/

Creation of the Department of Homeland Security. (n.d.). Retrieved from Homeland Security: http://www.dhs.gov/creation-department-homeland-security

Kansal, A., Goraczko, M., & Zhao, F. (2007). *Building a Sensor Network of Mobile Phones.* Cambridge, MA.: Microsoft.

Macy's Thanksgiving Day Parade. (2011). Retrieved from about.com: gonyc.about.com/od/thanksgiving/tp/2011-Macys-Thanksgiving-Day-Parade

Measurement: Activity: How Much Is Present? (n.d.). Retrieved from Guidance for Radiation Accident Management: http://orise.orau.gov/reacts/guide/measure.htm

Nave, C. R. (2014). *Inverse Square Law, Radiation*. Retrieved from HyperPhysics: http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html

Nelson, R. (2012). *Concept of Operations for Wireless Sensor Networks.* Naval Postgraduate School.

Oberhagemann, D. (2012). *Static and Dynamic Crowd Densities at Major Public Events.*

Park, J. (2005). *Management of Ubiquitous Sensor Networks.* Kyungpook National University.

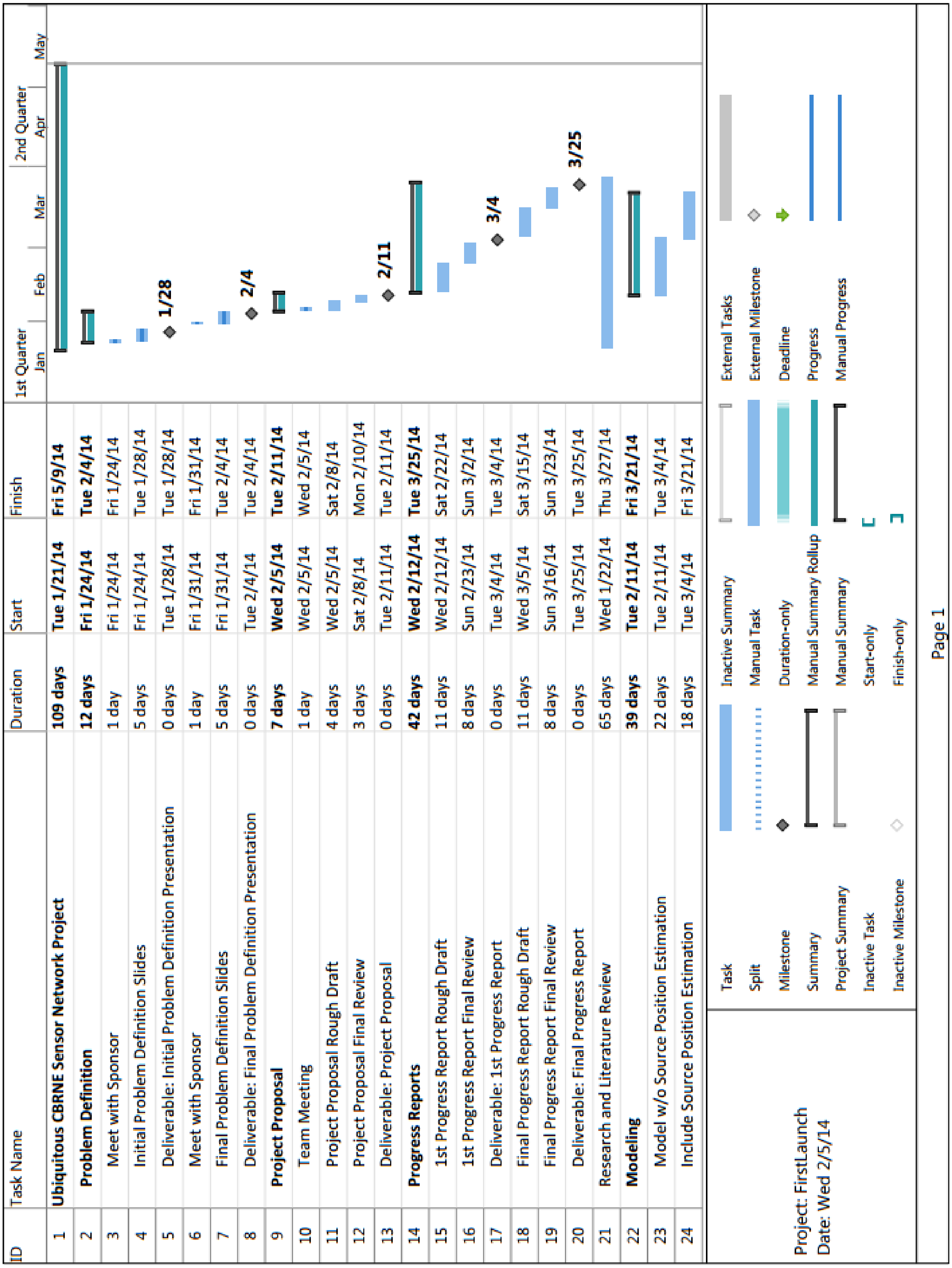
Radiation Basics: How Can You Detect Radiation? (n.d.). Retrieved from Health Physics Society: http://hps.org/publicinformation/ate/faqs/radiation.html

Stankovic, J. (2006). *Wireless Sensor Networks.* University of Virginia.

Still, K. G. (2014). *Crowd Risk Analysis*. Retrieved from GKStill.com: http://gkstill.com/

Sutter, J. (2010). *Smart Dust Aims to Monitor Everything*. Retrieved from CNN: http://www.cnn.com/2010/TECH/05/03/smart.dust.sensors/

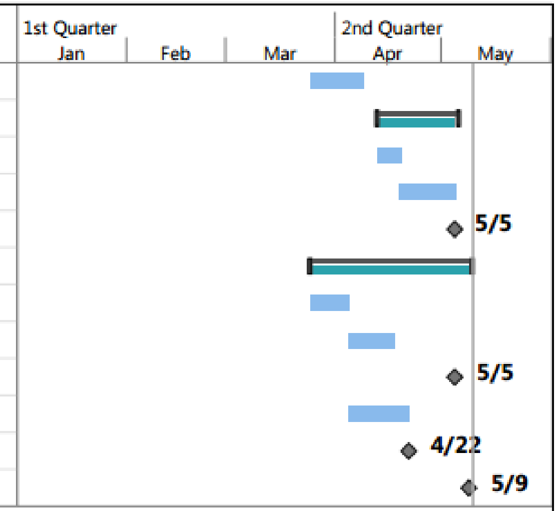
Appendix



ID	Task Name	Duration	Start	Finish
1	**Ubiquitous CBRNE Sensor Network Project**	**109 days**	**Tue 1/21/14**	**Fri 5/9/14**
2	**Problem Definition**	**12 days**	**Fri 1/24/14**	**Tue 2/4/14**
3	Meet with Sponsor	1 day	Fri 1/24/14	Fri 1/24/14
4	Initial Problem Definition Slides	5 days	Fri 1/24/14	Tue 1/28/14
5	Deliverable: Initial Problem Definition Presentation	0 days	Tue 1/28/14	Tue 1/28/14
6	Meet with Sponsor	1 day	Fri 1/31/14	Fri 1/31/14
7	Final Problem Definition Slides	5 days	Fri 1/31/14	Tue 2/4/14
8	Deliverable: Final Problem Definition Presentation	0 days	Tue 2/4/14	Tue 2/4/14
9	**Project Proposal**	**7 days**	**Wed 2/5/14**	**Tue 2/11/14**
10	Team Meeting	1 day	Wed 2/5/14	Wed 2/5/14
11	Project Proposal Rough Draft	4 days	Wed 2/5/14	Sat 2/8/14
12	Project Proposal Final Review	3 days	Sat 2/8/14	Mon 2/10/14
13	Deliverable: Project Proposal	0 days	Tue 2/11/14	Tue 2/11/14
14	**Progress Reports**	**42 days**	**Wed 2/12/14**	**Tue 3/25/14**
15	1st Progress Report Rough Draft	11 days	Wed 2/12/14	Sat 2/22/14
16	1st Progress Report Final Review	8 days	Sun 2/23/14	Sun 3/2/14
17	Deliverable: 1st Progress Report	0 days	Tue 3/4/14	Tue 3/4/14
18	Final Progress Report Rough Draft	11 days	Wed 3/5/14	Sat 3/15/14
19	Final Progress Report Final Review	8 days	Sun 3/16/14	Sun 3/23/14
20	Deliverable: Final Progress Report	0 days	Tue 3/25/14	Tue 3/25/14
21	Research and Literature Review	65 days	Wed 1/22/14	Thu 3/27/14
22	**Modeling**	**39 days**	**Tue 2/11/14**	**Fri 3/21/14**
23	Model w/o Source Position Estimation	22 days	Tue 2/11/14	Tue 3/4/14
24	Include Source Position Estimation	18 days	Tue 3/4/14	Fri 3/21/14

Figure 1 - Project Plan Page 1

ID	Task Name	Duration	Start	Finish
25	Analysis	15 days	Tue 3/25/14	Tue 4/8/14
26	**Website**	**23 days**	**Sun 4/13/14**	**Mon 5/5/14**
27	Research Web Page Design	7 days	Sun 4/13/14	Sat 4/19/14
28	Site Development	16 days	Sat 4/19/14	Sun 5/4/14
29	Deliverable: Final Website	0 days	Mon 5/5/14	Mon 5/5/14
30	**Final Report and Presentation**	**46 days**	**Tue 3/25/14**	**Fri 5/9/14**
31	Final Report Rough Draft	11 days	Tue 3/25/14	Fri 4/4/14
32	Final Report Review	13 days	Sat 4/5/14	Thu 4/17/14
33	Deliverable: Final Report	0 days	Mon 5/5/14	Mon 5/5/14
34	Final Presentation Slides	17 days	Sat 4/5/14	Mon 4/21/14
35	Final Presentation Dry Run	0 days	Tue 4/22/14	Tue 4/22/14
36	Deliverable: Final Presentation to Faculty and Sponsor	0 days	Fri 5/9/14	Fri 5/9/14



Project: FirstLaunch
Date: Wed 2/5/14

Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

Page 2

Figure 2 - Project Plan Page 2