Human-In-The-Loop Simulation Testbed for Wireless Sensor Networking

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Abstract - **Wireless sensor networks (WSNs) involve the deployment of small, inexpensive, and limited capability devices to gain information about a given location. This project focuses on intrusion detection in any environment to test the limitations and capabilities of WSNs. Specifically, the goal is to detect any intrusive behavior with a limited number of human resources. The capstone team developed a simulation testbed program using C# to duplicate real life surveillance scenarios. The simulation technique can be applied in a variety of settings including agricultural monitoring, disaster relief, public utilities, security surveillance (commercial and private), traffic control, and military operations. The overall motivation behind designing this project involved reducing the number of personnel needed to monitor any given area and gain intelligent information to make informed decisions.**

I. Introduction

THIS capstone project focuses on the design and development of a computer-based simulation component of a human-in-the-loop experiment. One of three integrated capstone projects, simulation project assesses the capabilities and limitations of rapidly reconfigurable WSNs. The overall experiment includes both a simulated (virtual) portion and a live demonstration. The live demonstration consists of physically deploying a WSN in experimental surveillance situations with human role-playing actors (intruders, security officers, and commanders) to monitor and protect a real building and the computer-based simulation of additional buildings. The overall experiment will integrate real-time information along with simulated information. Because surveillance situations are dynamic and highly unpredictable, a simulation testbed capable of supporting a rich and easily reconfigurable set of experiments is required [13]. Intelligence communities are also increasingly relying on new and innovative technologies to optimize transmission of data through WSNs in order to effectively allocate their efforts in mission-critical systems.

Our individual capstone team's goal was to implement the simulation environment by developing a simulation testbed which depicts real life scenarios of protected areas in a grid-like structure. The grid-like structure will imitate the floor of a building or the outside of a given area. More specifically, this is created using Graphical User Interface (GUI) that allows a user to input certain characteristics of the environment and parameterize the grid-like structure. The given dimensions are inputted into a Wireless Sensor Network Simulator, which allows monitoring of any given area. Furthermore, the simulation is used in the overall experiment by integrating the output of the simulation in a hybrid computer-based simulation and live demonstration. The aggregated data will then be analyzed in terms of network traffic, workload, and time-delay of the WSN including a discussion of the pitfalls we encountered in running the human-in-the-loop simulations.

The integrated capstone team has also developed a use-case scenario which will test the limitations of the WSN by integrating real-time data and simulated information. In the live portion, streaming video from cameras running a detection algorithm will traverse the network. The video will consist of intruders and guards carrying out their objectives as outlined in the use-case scenario. The virtual environment, however, will be inputting arbitrary data that will be used simply to overload the network to test the limitations of the WSN. The virtual environment aims to save a significant amount of money and time by simulating the scenario rather than physically monitoring and gathering data on several buildings.

The simulated environment will allow for monitoring of any given area and be able to detect any intrusive and/or dangerous behavior and allow the user to act accordingly. Additionally, the task will be to determine whether WSNs can be implemented in a building surveillance setting to be more effective than using more human resources to monitor the same area.

II. Review of Technical Literature

Manuscript received April 10, 2007. This work was supported in part by the Systems and Information Engineering Department at the University of Virginia, Charlottesville, VA. Paper titles should be written in uppercase and lowercase letters, not all uppercase. Avoid writing long formulas with subscripts in the title; short formulas that identify the elements are fine (e.g., "Nd–Fe–B"). Do not write "(Invited)" in the title. Full names of authors are preferred in the author field, but are not required. Put a space between authors' initials.

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WSNs are computer networks containing autonomous devices that use sensors to cooperatively monitor physical conditions in geographical areas [6]. Originally designed for military application, WSNs are beginning to be deployed in a variety of fields, including agriculture, healthcare, traffic control, and habitat monitoring [3].Each network contains many 'nodes' which consist of sensors attached to a motherboard, capable of transmitting information through a radio transceiver. The radio transceivers use wireless protocols to communicate with one another. Wireless technology rapidly continues to grow but still faces limited power, processing, storage, and communication capabilities [22].

WSNs are divided into two large networks—a data acquisition network and a data distribution network monitored by a management center. The data acquisition network gains information from the wireless devices, in our case, the wireless sensors. Intuitively, the trade-offs to wireless networks are the power requirements for the sensors and motes (as well as the connection speed) [38]. Experiment results from using these devices remain scarce or unfeasible due to high deployment costs, limited resources, or current state of technology [3]. Therefore, simulation environments can serve as tools to imitate above described processes, which involve only a few characteristics or behaviors, instead of monitoring physical systems [12, 16].

Simulation testbeds create a cheap and efficient virtual model to collect data from sensors to learn performance optimization. Instead of acquiring several personnel and resources to gather experimental information, large amounts of money and time can be applied towards other areas of research. Current WSNs applications exist in law enforcement, military, transportation, environmental monitoring, public utilities, and other industries [6]. WSNs currently utilize basic simulation techniques but require further improvement to create a grid-like simulation technique applicable to any building in any location [G. Learmonth, personal communication, September 28, 2006]. The creation of a rapidly deployable and reconfigurable sensor network can help target any of the above-mentioned areas and simulation can assist in customizing and improving each location's preferences. Due to the large and complex behavior of WSNs and their applications, simulation can aid in identifying important factors and modifying the model to reach optimal performance [20]. The main purpose of sensor networks involves operating at the highest efficiency level possible to provide critical information to the end user [18].

III. Simulation Testbed

Use Case Scenario

The use-case scenario that all three capstone teams developed provided a complete description of what the audience will see in the live demonstration as well as in the simulated environment. It includes a narrative of a mission-critical scenario in which the role playing actors (intruders, guards, and a base commander) interact and are attempting to achieve their goals and objectives. A collection of re-deployable surveillance components (cameras, computing platforms, and communication equipment), are also described which are placed throughout the given area. These are configured to provide constant monitoring and notification at a centralized base station of any unusual activity (as in the MITL scenario). The base station commander can view real-time streaming video output from any of the deployed cameras and use this information to direct the activities of a small number of mobile officers. Voice communication between the base commander and guards will be the only link determining whether or not the officer 'detains' the intruders.

The use case scenario also describes a counter-terrorism scenario in which a group of terrorists attempt to infiltrate a highly secured area. The integrated scenario is described in detail and available in Appendix A. In one of the buildings of that site, there is a very important object in one of the rooms of the area. To infiltrate this area and to escape successively with the object is the main objective of the intruders. However, there are also other objects in two other buildings which serve as secondary objectives to the intruders. Appropriately, there will be two guards per building and their objectives will be to protect the designated target area and detain the intruders. The guards will have communication devices by which they talk with a base commander who is receiving images of intruders. When the base commander is notified of a detection, he will issue commands to the guards. Furthermore, the base commander will have a visual web interface which will show the layout of the floor plan of the buildings and cameras, notify him of events such as detections, and provide options for showing streaming video/ snapshots. In addition, the base commander will have access to a database receiving camera information, time and location of detection, etc.

The overall demonstration will include two simulated buildings and one real building. This means that when the base commander is notified of a detection in one of the buildings, it may be a simulated detection from the virtual portion (the simulation testbed) or a detection from the real-time portion that will be occurring in the real-time demonstration. The base commander, however, will not know whether the streaming video and camera information is from a real building or a simulated building. This information will serve to overload the WSN with camera information and video imagery data when there are detections from the simulated and real buildings. The aim then, will be to analyze the data traffic with network monitoring applications as well as the cognitive limitations of the base commander and guards. Refer to *Appendix B* for a complete description of the use-case scenario.

Reconfigurable Simulation Program

While the use-case scenario that we developed focuses on security surveillance and intrusion detection, one of the

main objectives for the simulation testbed was that it should be easily reconfigurable. This meant that the simulation testbed we created must be able to be used in various applications of WSN simulation, as well as be flexible enough to simulate any given area. For this reason, our capstone team decided that it would be up to the user to input the simulation parameters. For example, the number of cameras, locations of cameras, size of the area, length and width of any obstructions, etc. would all be required by the simulator in order to 'draw' a grid-like representation of the area in mind. To give an intuitive feel to our simulator, we created a GUI, as seen in Figure 1, for the user which then converted the inputs into a ready-made XML file to be loaded into the simulation engine.

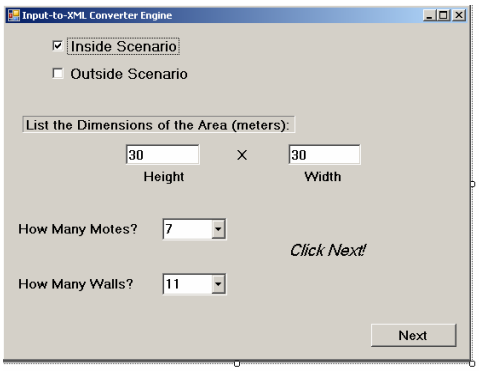

Figure 1: Input-to-XML Converter Engine

The 'XML-converter-engine' was a simple GUI that provided user input in the form of textboxes and drop down menus to create the XML file. Inputs such as x, y coordinates of cameras, target area(s), intruders, and walls were all inputted using this form. The only drawback that the XML engine poses is that the walls were difficult to create because the only inputs to the XML engine (and simulation program) were x and y coordinates as well as length and width parameters. This meant that the user would still need a floor plan or a blueprint to 'draw' the walls correctly using those parameters. However, given a blueprint or floor plan *with* dimensions marked, this would require only a small number of calculations.

Wireless Sensor Network Simulator

The wireless sensor network simulator was an application that resulted from aggregating last year's capstone project with the requirements of simulating a realistic surveillance scenario [7]. The WSN simulator, as seen in Figure 2, was used to emulate sensor networks under different environmental scenarios.

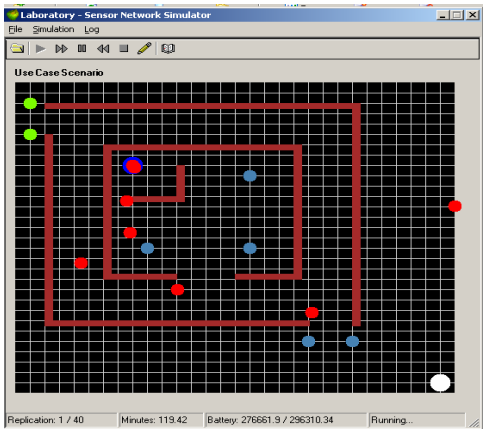

Figure 2: Wireless Sensor Network Simulator

The simulation created different types of environments by reading in scenario files expressed in XML and then represented those parameters in a grid-like graphical representation. The grid-like structure is ideal for discrete-event simulation where all users will be familiar with Cartesian coordinates to represent all objects in the simulation. The WSN simulator functions by use of simulated timers, which are used to determine when enemies and guards move, when they're created, and how long they wait at targets before leaving them.

Integration

The third task was to discuss and develop a way that we could take the data from the simulation and integrate it with the live demonstration. The decision made by all three teams was to create a web database that keeps track of all of the data—whether outputted from the virtual simulation or from the live portion. This meant that to the user or base commander in the simulation, the network traffic being generated from the virtual simulation was no different than real-time images being sent from the live portion of the experiment. Consequently, our individual capstone team needed information about what precisely was to be inputted into the database and therefore needed to be incorporated into the design of the database. The other two teams, one concerned with information management and the other with capturing, compressing, and distributing images, were also significantly involved with the specifications of the virtual simulation. Ultimately, the other two teams worked together to specify the bit rate and bandwidth values which would be used in the virtual portion to simulate a real-world scenario of images traversing a network.

The advantage of the web-driven database was that it could be easily accessible to anyone on the network, and therefore our team could simply connect to a database and output data in an organized format in order to output data such as detection events from the simulation.

One of the more important features of this live demonstration was that the data being outputted (from either the live demonstrations or virtual simulation) needed

to be displayed in a reasonable and intuitive fashion to the user (the base commander). As an integrated capstone team, we created a web interface which accesses the database during the simulation. The interface we designed was similar to a windows explorer form where the user could click on a specific building and get information on the building such as the number of floors, number of cameras, and a displayed image of the floor of the building from the database. The cameras, if tripped, would be alerted to the base commander by a flashing red camera icon displayed on the image of the floor of the building. The base commander could then request a video feed. If the detection was made in the simulation, a java applet would run a pre-recorded video at the bit rate specified by the information management [capstone] team. If the detection was made in the real-time demonstration, however, the video would be a live feed from one of the cameras. The base commander would then contact one of the guards and issue him/her a command. The web driven database and the web interface serves as the link between our simulation testbed and the overall experiment that will ultimately test the constraints of the wireless sensor network for the purpose of intrusion detection.

IV. Observation and analysis

This section will be divided into two categories: parameter observations and program analysis. First, the simulation team made observations on the parameter limitations of the simulation program. After running the simulation and observing the data from the physical wireless camera network, the team concluded that the time delay for information transfer would not be realistic. If an intruder in the simulation set off a camera, by the time the video stream reached the base commander, the intruder would have already moved to another part of the building. This time delay can be attributed to bandwidth constraints. If an intruder walks through a building and trips six cameras, the amount of videos being streamed to the base commander would be too much information for a wireless sensor network, especially if multiple intruders in multiple buildings are being simulated. Finally, the greatest concern regarding camera networks may be the information gap; the base commander has a limited view of the situation using the cameras. The commander's ability to react to an intrusion by sending guards to inspect the area may be less efficient than having a guard already posted where the wireless camera would be located.

The simulation team conducted an analysis of the simulation program when integrated with the other two teams. Several improvements to the final demonstration were possible. First, the web interface, as seen in Figure 3, does not enhance the base commander's ability to make decisions using the limited data from the camera network. Because of time delay and technology limitations, the web interface severely restricts the base commander's ability to view all intruder information. The current implementation of video streams coming from the simulation program is quantized. Further work needs to be done to dynamically change the resolution of videos from the simulation program. In addition, the XML files produced using building specifications may not be sufficient. Currently curved walls are not supported by the simulation program. Finally, the guards in the simulation do not properly reflect the actions of an actual human. The simulation program directs the guards to approach the objective. A human guard might perform other actions to detain the intruder such as waiting at the entrance to the objective. Such considerations must also be coded into the simulation.

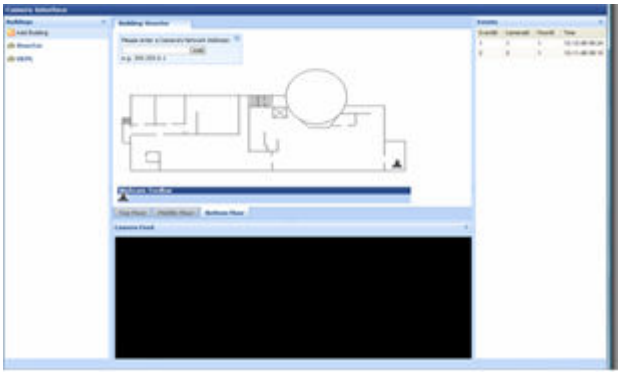

Figure 3: Integrated Web Interface

Appendix A

Intelligence has been gathered about a potential terrorist attack on a domestic Nuclear Reactor Building (NRB) complex located at the University of Virginia. The facility's staff has been evacuated, and our team has been deployed to quietly provide security for the facility. The terrorist group that is planning the intrusion is well known and capturing the intruders for interrogation is an objective.

There are three buildings that we need to monitor with limited resources of two guards at each building and a base commander watching all three buildings. The Nuclear Reactor Building (NRB) will serve as the physical building while the other two buildings will be simulated using simulation software. A Wireless Sensor Network (WSN) will be created using the real buildings and simulated building to test bandwidth, time delay, and maximum capacity of the network.

The main area of protection is the plutonium that is stored at the facility in the NRB on the bottom floor. Similarly, the simulation buildings also have a target that the intruders want to capture. If these materials get into the wrong hands, it could cause an international disaster. There are other areas throughout each facility which contain information that needs to be protected. These areas include filing rooms, offices, and storage areas called side objectives in our scenario. The layout of the buildings and facility are well known by the team, and blueprints and floor plans are available.

Across the three buildings, we have deployed a total of seven people. Two guards deployed at each building – NRB

and two simulated buildings. Additionally, a base commander is in a remote location that monitors the three buildings. The teams will be able to communicate to the base commander who will have access to video and sensor information. The roaming guards will be setting off sensors, but all team members will be in a uniform that will be easily identifiable by looking at them on a video feed. Team members will also have access to the video information through PDAs; however the quality is not very good. There are too many areas that need to be protected to deploy a guard to each station. The teams will need to rely on information from the base commander in order to control their movements.

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Thompson, G., Vaswani, A., Walthall, B. *Computer Vision Information Systems for Wireless Surveillance* (2007).

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