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Securing the United States' power infrastructure

August 2015

SF Happenny

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Abstract

The United States' power infrastructure is aging, underfunded, and vulnerable to cyber attack. Emerging smart grid technologies may take some of the burden off of existing systems and make the grid as a whole more efficient, reliable, and secure. The Pacific Northwest National Laboratory (PNNL) is funding research into several aspects of smart grid technology and grid security, creating a software simulation tool that will allow researchers to test power distribution networks utilizing different smart grid technologies to determine how the grid and these technologies react under different circumstances. Demonstrating security in embedded systems is another research area PNNL is tackling. Many of the systems controlling the U.S. critical infrastructure, such as the power grid, lack integrated security and the networks protecting them are becoming easier to breach. Providing a virtual power substation network to each student team at the National Collegiate Cyber Defense Competition, thereby supporting the education of future cyber security professionals, is another way PNNL is helping to strengthen the security of the nation's power infrastructure.

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Acronyms and Abbreviations

ns-3: Network Simulator 3

Contents

1.0 Introduction

According to Edwin Hill, president of the International Brotherhood of Electrical Workers, "the average age of power transformers in service is 40 years, which also happens to be the average lifespan of this equipment."[1] In addition to the age of U.S. infrastructure, the amount of investment in the current grid infrastructure is significantly less than what its maintenance requires and is even farther from growing it to meet the increasing demands we place on it. These factors, plus the increasing sophistication and proliferation of cyber attacks, puts the United States' power grid at risk of massively impactful cyber attacks. The risk is so great that the head of the National Security Administration and U.S. Cyber Command, Michael Rogers, said in November 2014 that it is "only a matter of the when, not the if, that we are going to see something traumatic" happen to the U.S. power grid.[2] In particular, Rogers said that China and "one or two" other nation states are capable of launching a cyber attack that could shut down the entire U.S. power grid in addition to other critical infrastructure.

Fortunately, work on improving the U.S. power infrastructure has begun with the development of smart grid technologies that will help upgrade the power grid into the 21st century and increase the efficiency, resiliency, and security of these critical power systems. PNNL has many research programs to support the development of smart grid technologies and help secure U.S. critical infrastructure. One project aims to develop software that will more easily allow researchers to investigate ideas in simulated power grids utilizing smart grid technology. Another project will demonstrate the use of a cheap and common microchip to provide security to the embedded computing systems controlling the physical systems that make up the power and other critical infrastructure. A third project will provide an emulated power substation environment for teams of college students to defend against cyber attacks at the 2015 National Collegiate Cyber Defense competition. Each of these projects will be discussed in detail in the following sections.

2.0 Integrated power grid simulator

2.1 Overview

As part of PNNL's goal to improve the reliability and security of the nation's power infrastructure, PNNL researchers wish to investigate new distributed control paradigms under realistic conditions. However, to simulate all of the relevant domains and technologies involved in the power grid, multiple simulators must be integrated and executed together. The smart grid technologies used in these new distributed control paradigms include Internet-connected power meters that can decide automatically, based on energy price, when to consume energy and communicate these decisions to other power meters, distribution systems, and customers. This level of communication will enable more efficient transmission of electricity, reduce peak demand, and improve grid resiliency and security.[3] Our team is developing a modeling language that encompasses the attributes of interest across all the simulators. This reduces the burden of understanding all of the details of each simulator configuration language, eliminates errors of mapping items between simulators, and makes researchers more efficient.

2.2 ns-3

The Network Simulator 3 (ns-3) is a free, open-source discrete-event network simulator aimed at educational and research use.[4] ns-3 can be used to simulate many different network protocols, including Ethernet, LTE, Wi-Fi, and 6LoWPAN, a wireless device-to-device standard developed for low-power Internet of Things devices.[5] ns-3 can also connect to arbitrary data sources, such as a real networking device like a physical router or a virtual source like Internet traffic from another simulator, and has functionality for recording information about the simulated network. This combination of free access and versatility makes ns-3 an appealing choice for use in projects like ours where our modeling language will be used to test many different technologies and hypotheses.

The purpose of using ns-3 in our project is to provide a high-fidelity, configurable virtual network over which the smart grid devices can communicate. Without a network simulator, communication between smart grid devices was instantaneous and perfect. This may not sound like a problem, but networking in the real world is far from instantaneous and definitely not perfect. Data takes time to move along physical media and can get bogged down in traffic, adding latency to the data transfer. Also, data are lost all the time in physical networks, necessitating a resend of the original data or some error management on the receiving end, thus adding more time and complexity to the communication channel. Network simulators account for these delays and imperfections, providing a more accurate representation of physical network conditions. This increased accuracy provides researchers with a truer idea of how the smart grid technologies they are testing will respond in the real-world.

2.3 Progress and outcome

Our team is currently testing an early version of the modeling language from a researcher's perspective. The main goal is to evaluate how well scientists and engineers without significant programming experience can use the tool to create a new model of a neighborhood with a smart power distribution system. Fully randomized home generation (i.e., slightly different energy efficiency and usage for each house to account for variations between designs, appliances, human use, etc.) has not yet been implemented, and the ns-3 networking component is limited to Ethernet-like connections. However, we will still be able to gain valuable feedback from testing this early version as it will provide a better idea of what is and is not working in terms of user interaction. Moving forward, we will use this information to guide the development of the software to ensure it is easy to use by its intended audience as we continue to add more features to the language.

3.0 Embedded systems security

3.1 Overview

Much of the hardware that runs the United States' critical infrastructure—including power, water, and communication systems—is decades old and has few, if any, built-in security provisions. Once a cyber attacker penetrates the security of the control system network that houses the embedded cyber-physical devices, they generally have full access to these devices that run physical systems like fans, pumps, and more. Therefore, building security into these embedded systems is crucial. One way to provide some security is through a Trusted Platform Module (TPM), a cheap microchip that contains dedicated cryptographic processors and secure storage, which has been used in enterprise-class computers for over a decade. TPMs can provide several processes for providing different types of security and authentication. Measured boot, for example, uses the TPM to check that the pre-boot environment has not been modified by malware and creates a chain of trust that successively verifies that each software layer running on the device has also not been modified.[6] After the values obtained by hashing each piece of software have been verified as correct, they are sealed in a storage unit on the TPM to preserve a signature of the valid state of the software stack. This storage is also used to store securely the keys used for encryption/decryption and signing of certificates. Another example of a function a TPM can provide is attestation, "the process by which a platform can cryptographically prove to another platform that it is in a particular state."[6] Attestation can be used to ensure that a device has not been tampered with before authenticating the device on a network.

For this project, we are using two BeagleBone Black development boards and two CryptoCapes that adds a TPM, among other cryptoprocessors, to the BeagleBone base board.[7, 8] The goal of the project is to demonstrate the ease of setting up and using a TPM to help protect embedded systems. Specifically, we want to use the TPM to certify that software installed on the BeagleBone to emulate the programmable logic controllers (PLCs) that control the physical devices in the power grid has not been modified before performing critical tasks, such as opening a breaker switch. The plan to achieve this goal is to document the setup of the TPMs and use them to attest the integrity of the software installed on the BeagleBones.

3.2 Progress

Work on this particular project has been limited due to demands from other projects. Currently, the BeagleBone boards and TPMs have been configured and are bootable and useable. The next step is to setup trusted boot with the TPMs, install the PLC emulation software, and add this software to the stack verified by the TPM.

4.0 National collegiate cyber defense competition

4.1 Overview

Started in 2005, the Collegiate Cyber Defense Competition (CCDC) is a system of events that throw teams of college students into administrative and protective roles with the job of defending an existing commercial network against professional hackers.[9] The students' goal is to preserve user access to services such as email and web access while managing business decisions and defending the network against sophisticated attacks. A series of regional competitions produces ten semi-finalist teams that participate in the yearly National CCDC (NCCDC) event in Texas.

The scope of this third project is to provide an emulated power substation computer environment to each team at this year's NCCDC on 24-26 April 2015. To do this, we are using three Raspberry Pis per team to represent three PLCs that communicate between the substation control room and the power breaker switch. We are modeling this switch with an Arduino that is only accessible via the Raspberry Pis. In the control room, we will have several virtual machines (VMs) set up for various tasks, including controlling and monitoring the Raspberry Pis and Arduino, monitoring the VMs, and recording the data coming from the Pis and Arduino. This setup is an accurate representation of a real world substation control room environment and will give the students hands-on experience at administering and protecting this type of environment.

4.2 Progress and outcome

Our goal is to provide a reliable, error-free environment for the college students to gain experience in defending cyber attacks. The systems we provide will make up the majority of the teams' area to defend as well as be a major source of the scoring information used to rank the teams at the end of the competition. Failure in our systems would therefore be a huge problem for the affected team(s) and the competition as a whole.

Unlike the other two projects discussed earlier, this one has a strict deadline of 24 April 2015 as that is when the 2015 NCCDC begins; however, we will have all of our systems ready to ship a week or two earlier. As of this writing, we are preparing to ship one set of Raspberry Pis representing the cyber-physical control systems and nearly all of the virtual machine servers to the NCCDC team in Texas. Aside from a few minor connection issues to be resolved, we are making great progress towards this milestone and our overall goal of the smooth operation of our systems for 3 days at the competition.

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