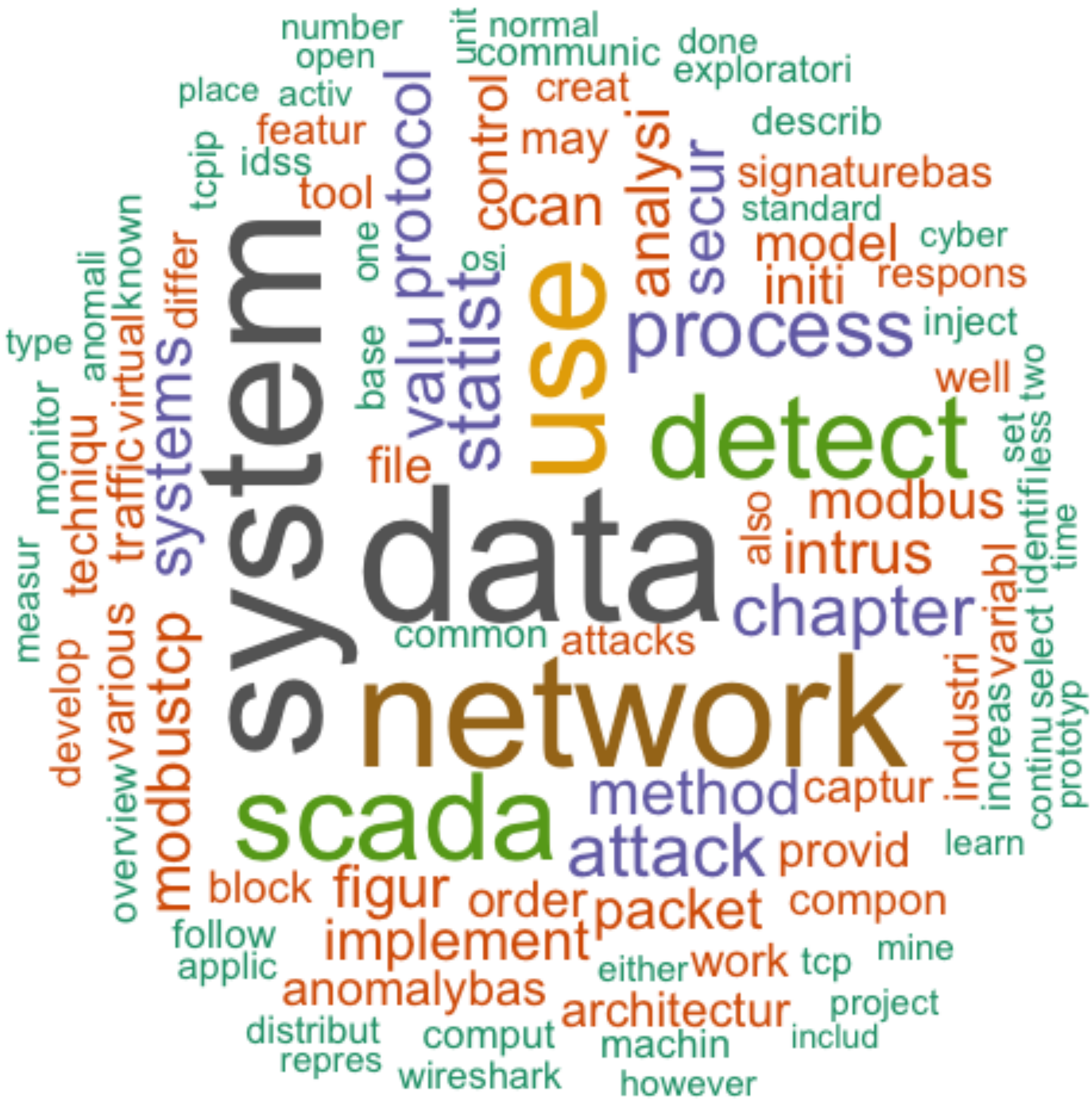
Diateam
SCAD@COPS
A Hybrid Network Intrusion Detection System

Lisa MALIPHOL



Diateam: SCAD@COPS
A Hybrid Network Intrusion Detection System

by

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In memory of my late mother, Pisamai Maliphol, if only she could have witnessed not only her latest grandchild, but to see me make it through the completion of this masters degree. In many ways, these two years were part of the healing process after her loss. She would have been extremely proud.

This work is also dedicated to my children, Mintra, Samya, and Lucien, may they never cease to continue and to have the motivation and curiosity to learn, no matter how late in life.

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Abstract

1 Introduction

Supervisory control and data acquisition systems (SCADA) are one type of industrial control system (ICS) put in place for monitoring and controlling industrial processes, such as those in the energy or manufacturing sectors. Originally, these systems were isolated and used proprietary protocols, whose security relied predominantly on obscurity. As SCADA systems have moved towards open standards and have become more interconnected to traditional information technology systems, these critical systems have also become increasingly exposed and targeted to cyber attacks.[Zhu2010][Zhu2011]

To secure SCADA systems, intrusion detection systems (IDS) are put into place with the purpose of observing, analyzing and detecting any malicious activity, which are then alerted to, and reviewed by, security analysts. Most IDSs found in the market-place are commonly network, signature-based IDSs. Anomaly-based detection systems are relatively immature, however, they provide a greater possibility of detecting unknown attacks. Signature-based systems can only detect known and identified signatures of attacks.

The trade-off between the two types of systems, signature-based and anomaly-based, are predominantly in the the accuracy with which they can detect a real attack, or anomaly. Although signature-based systems that have been properly configured rarely raise false alarms, unlike anomaly-based systems, they are less capable in detecting novel attacks. Additionally, these intrusion detection systems themselves are also exposed to the same security issues as the systems they are trying to secure.

Diateam has proposed an architecture and implemented a prototype of a hybrid IDS under the project SCAD@COPS. Based on the contributions of [Chifflier2014] and [Diallo2014], the prototype integrates the architectural and signature-based aspects as described in their work, and where the following constraints were taken into consideration in the design of SCAD@COPS: network-based passive only; the IDS should not interfere with, nor modify the SCADA system only TCP/IP and Ethernet data are analyzed.

This work is divided into the following major sections:

- Section 2 provides an overview of SCADA systems
- Section 3 provides some basic networking principles
- Section 4 briefly considers a few common cyber attacks
- Section 5 discuss intrusion detection systems
- Section 6 summarizes different approaches for detecting network intrusions
- Section 7 lists the tools utilized in this work
- Section 8 describes the data source used in this work
- Section 9 gives an overview of the exploratory data analysis
- Section 10 describes the prototype architecture and implementation
- Section 11 outlines the statistical measures and features used
- Section 12 describes the testing and evaluation process
- Section 13 summarizes and concludes

2 Overview of SCADA Systems

2.1 ICS

An Industrial control system (ICS) comprises such systems as supervisory controls and data acquisition (SCADA), distributed control systems (DCS), and smaller systems such as programmable logic controllers (PLC) that are control systems predominantly used in industrial production.

ICSs were initially developed to meet the requirements of performance, reliability, safety and flexibility. They existed prior to the advancement in computer and network technology, such as public and private networks, desktop computing, or the Internet. Since ICSs remained rather isolated and obscure, the dangers of cyber security were less, or non-existent.

Typically industrial control systems are continuously operational and commonly serve vital public services and infrastructure, thus preventive security measures must be put into place. The compromise of SCADA systems may have negative consequences including, but not limited to, substantial damage to the environment, significant risk to human safety and health, and financial and production losses.

2.2 SCADA

A Supervisory Control and Data Acquisition (SCADA) system is an industrial control system (ICS) used for monitoring equipment and controlling processes in industries such as electrical, water, and oil, as . The administration over a geographically widely distributed process can be directed from a central location at the master terminal unit (MTU) in SCADA systems. Changes to process controllers, the opening and closing of valves and switches, the monitoring and the measurement of information is administered from the MTU to remote terminal units (RTU). Due to their economy, versatility, flexibility, and configurability, programmable logic controllers, which are small industrial computers are widely used as RTUs.[Stouffer2006] The various components of a SCADA system is shown (Figure 1).

These systems have differing constraints and properties from those of traditional IT systems, the most prominent being that they are hard real-time systems that must always be available and run continuously without outage. Once the field devices have been put into place, they are normally left untouched, i.e., not rebooted and left running for years. This creates the problem of the systems being more susceptible to buffer overflow due to the accumulation of fragmentation.[Zhu2011]

Historically, SCADA systems resided on their own internal networks and were not connected to other networks. They used proprietary protocols, and were, therefore, less vulnerable to network attacks. However, over time as these systems adopted open standards and leveraged traditional enterprise systems to lower costs, to increase functionality and productivity, SCADA systems are also now increasingly exposed to internal and external attacks.

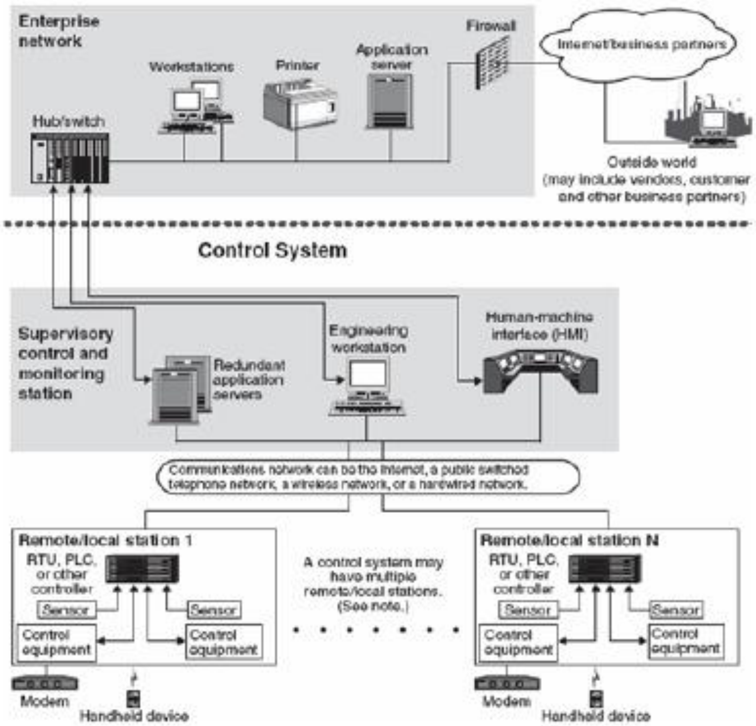

Figure 1: SCADA components [Zhu2010]

2.3 Traffic characterization

As seen in the comparative analysis done in [Barbosa2012-1], it is shown how the traffic greatly differs between SCADA and traditional networks. Most traffic is generated by automated processes in SCADA networks as opposed to human-generated traffic predominant in traditional networks. The traffic pattern generated in SCADA networks have been found to be fairly static and repetitive, with its network topology unchanging, or rarely modified. Also seen [Cheung2006] are a limited number of applications and protocols that run on industrial systems. Markedly seen over MODBUS traffic, the messages exchanged between PLCs are recurrent giving it a fixed pattern and relatively stationary process.[Goldenberg2013][Barbosa2012-2,3]

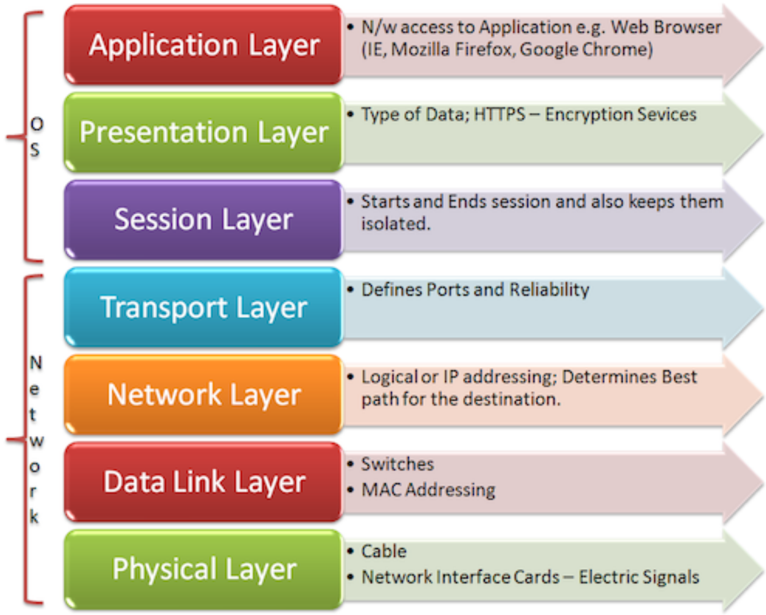

Figure 2: OSI Model

3 Networking Overview

In this section, a few fundamental networking terms are discussed. First, an outline of the OSI model is described, followed by the TCP/IP and MODBUS/TCP protocols.

3.1 OSI

Known as the Open System Interconnection (OSI) model, it was initially developed by the International Standards Organization (ISO) to define and characterizes the communication between computing systems. The OSI model, as shown in Figure 2 (OSI Model image source) is represented as layers, each one expressed as a protocol. Each layer serves the layer above it, and the lowest one being closest to the physical medium carrying the communication. Figure OSI Model depicts each layer and its role and responsibilities.

3.2 Protocols

As SCADA systems have become increasingly interconnected to enterprise networks, they operate over, and utilize the same protocols as previously discussed. Additionally, most SCADA appliances implement and use the MODBUS/TCP protocol, which run over the TCP protocol.

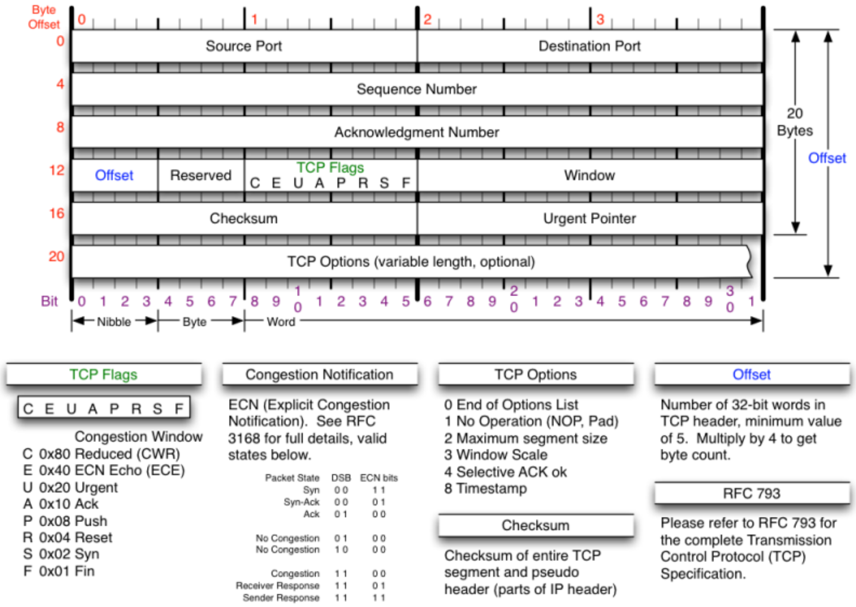

Figure 3: TCP Header

3.2.1 Transmission Control Protocol/Internet Protocol (TCP/IP)

Initially developed by the Defense Advanced Research Project Agency (DARPA) in the late 1960s, the Internet protocol suite was the result of the research and development of data transmission technologies in the United States that was used as a standard for military computer networking.

TCP/IP provides reliable, ordered and error-checked delivery of streams of octets between applications running on hosts communicating over an IP network. A detailed illustration of the TCP and IP headers can be seen in Figures 3 (Image credit: Max Baxter) and 4 (Image credit: Max Baxter).

3.2.2 MODBUS/TCP

The MODBUS/TCP protocol is an open standard and popular network protocol used for ICS devices. It is a messaging protocol located at the application layer that was designed to communicate with PLCs in industrial systems. However, due to the limited resources the PLCs have, it was created to be a simple protocol that provides no security against unauthorized commands or interception of data.[Modbus2012] Figure 5 gives an example architecture for MODBUS TCP communication.

The master initiates a request and the slave sends a response containing either data or error. The common implementations of MODBUS are over Ethernet networks (MODBUS/TCP) or Serial busses (MODBUS/RTU). Both forms of MODBUS contain the packet data unit (PDU), the component consisting of a function code and data.

Attached to the PDU is the application specific addressing and error checking, which together

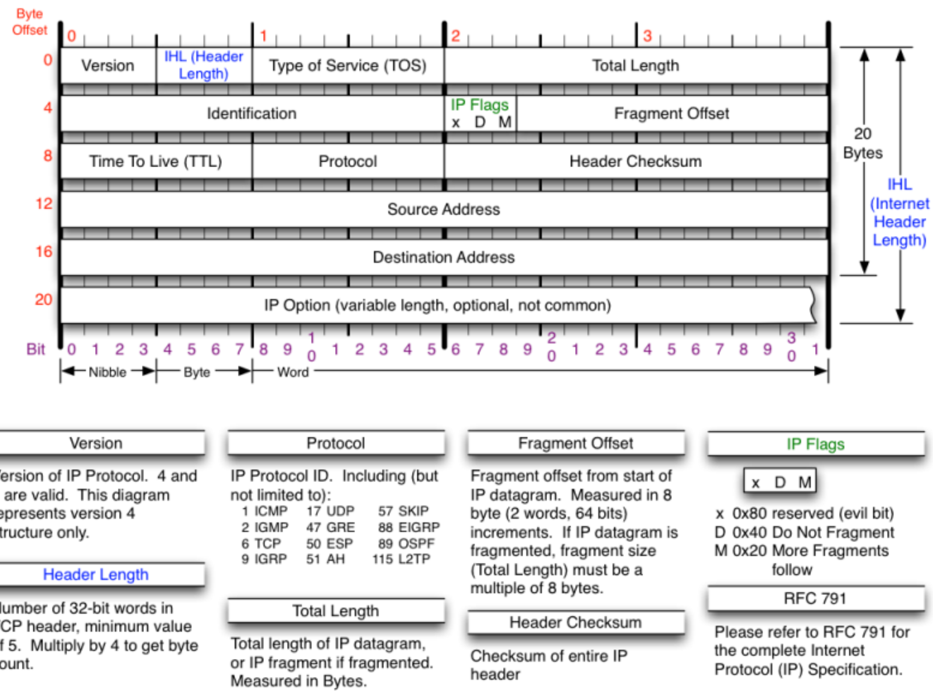

Figure 4: IPv4 Header

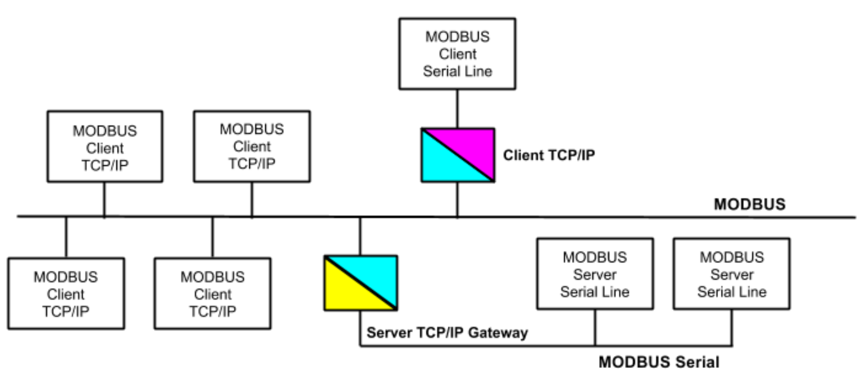

Figure 5: MODBUS TCP/IP Communication Architecture

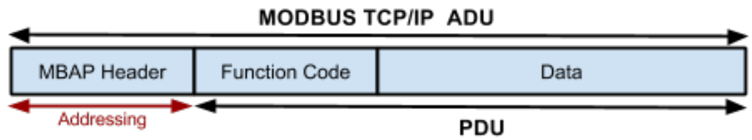

Figure 6: MODBUS/TCP Frame

comprise the application data unit (ADU). Specific to MODBUS/TCP, the ADU is encapsulated in the TCP packet. Thereby eliminating the need to include error checking in the MODBUS/TCP layer, it is left out from the MODBUS/TCP ADU. The MODBUS/TCP frame is depicted in Figure 6.

Included in the MODBUS Application Protocol (MBAP) are: - Transaction ID - 2 bytes - identifies request/response pairs - Protocol ID - 2 bytes - is always 00 00 for Modbus protocol - Length - 2 bytes - identifies the number of bytes in the following message - Unit ID - 1 byte - used to distinguish which slave is addressed when several slaves use the same IP address

The MODBUS/TCP transaction ID is reset to zero with each new TCP session. It is important to note that in identifying MODBUS conversations, port 502 is reserved for MODBUS communication. MODBUS requests are initiated from port 502 and MODBUS responses terminate at port 502.

As a result of using the simple design of MODBUS and its reliance on the TCP layer, security issues become apparent. With no authentication and authorization mechanisms, data integrity checks, or encryption, the SCADA network components provide no identity or permission verification, message content legitimacy, or confidentiality.

4 Common Attacks on SCADA

4.1 TShark

[Hadziosmanovic2010][Krotofil2013][Lemay2013][Rodrigues2011][Stouffer2006] define threats and vulnerabilities, security issues, as well as policies and best practices, and recommendations on how to best secure SCADA systems. However, cyber attacks continue to increase as SCADA systems become more exposed and as the attacks grow in sophistication. And specifically in regards to attacks on MODBUS TCP, little has been published, except for the work done by Digital Bond.[ˆ1] [ˆ1]: http://digitalbond.com

Leveraging existing enterprise network infrastructure, SCADA systems are also at risk to the same threats that typical IT systems encounter. In addition, as SCADA systems are upgraded less frequently and continue to run on legacy systems, they are rendered even more vulnerable to various attacks that may be prevented by deploying upgrades that address newer and known threats. In [Zhu2011], outlines and describes in detail the various methods of cyber attacks on software and hardware and ways of compromising SCADA systems.

The following provides an overview of common attacks that have been exploited against SCADA systems [Morris2013].

4.2 Command Injection

In regards to command injection attacks, the attacker may intercept and alter, or insert conceivably malicious commands that are then unknowingly executed in the system. Some known types of command injection attacks are SQL Injection and Cross-Site Scripting (XSS). False commands meant to alter the control and configuration in ICSs commonly seen are injected to modify and interrupt communication and processes.

More frequently seen in SCADA systems, MODBUS communication is intercepted, or more precisely, an attacker injects MODBUS functions intended to modify the industrial process.Since the MODBUS/TCP protocol was not designed with security taken into account and has no encryption or sophisticated security precautions, it is vulnerable to the manipulation of the function code or data field sent in the requests.

4.3 Response Injection

The nature of response injection attacks is that they perform unauthorized write requests. Commonly used in ICSs, polling is continuously done in order to audit the state of remote processes. Over the MODBUS/TCP, there is frequent request and response communication between the MTU and RTUs. Perpetrators may craft response packets that are subsequently inserted into the communication loop and if timed accordingly, is received as the first response to a query thereby rejecting further responses as invalid.

4.4 Denial of Service

In an attempt to render services unavailable and stop the proper functioning of a system, denial-of-service attacks either try to bring down and crash the service, or flood all resources preventing legitimate users from accessing the service. Attacks of this type on SCADA systems try to either reboot MODBUS servers or manipulate the controls to take them out of service. In other cases, an endpoint is overwhelmed to the point where it cannot take on further requests.

4.5 Reconnaissance

In a reconnaissance attack there is unauthorized reading of data, where this type of attack generally surveys a network and identifies connected devices in order to ascertain the network architecture and topology. Once the network is accessed by the perpetrator, they may carry out different levels of scanning over the network, such as address, port and points scanning. In the case of SCADA systems, with the MODBUS/TCP being the prevailing protocol used for ICS devices, function scanning is also done.

4.6 Zero-day Attacks

Attacks that exploit previously unknown vulnerabilities and security holes before a vendor can react and correct them via a patch are known as zero-day attacks. As deploying upgrades and patches to ICSs are relatively slow and infrequent, ICSs are highly susceptible to the weakness discovered in software or hardware before they are corrected. A well-known malware meant to target industrial PLCs, Stuxnet was designed to exploit an assortment of zero-day flaws.[Karnouskos2011]

5 Tools

5.1 Wireshark[1] - Network Traffic Analysis Tool

Developed in 1997 by Gerald Combs originally named Ethereal, Wireshark is now an Open Source GNU project. It is a network packet analyzer, or "packet sniffer", that captures and displays network packets.

Captured network packets are saved in the pcap file format and can be dissected and parsed by Wireshark in order to analyze its contents. An important aspect of Wireshark is that of its passive/monitoring nature and so does not send, manipulate, or modify the data passing over the network.

An initial packet capture file was created over simulated network traffic using Wireshark. Using its export facilities, various files were created for further analysis, with information such as TCP endpoints, conversations, etc.

5.2 TShark[2]

Another tool from the Wireshark suite is the command-line tool similar to tcpdump is tshark, a network protocol analyzer. In addition to capturing packet data over a live network, it is also capable of analyzing packets from an existing capture file. TShark was used to parse out various pertinent variables pertaining to the Modbus/TCP application protocol enclosed in the packet data.

5.3 UNIX Utilities

In order to further parse and transform the data, the UNIX utility tool sed, which supports the use of regular expressions, was also used.

5.4 R - Statistical Tool[3]

R is an Open Source programming language and environment used for statistical computing and graphics. Initially developed by John Chambers at Bell Labs as the S language in 1993, R was created as a freely available version under the GNU project by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand.

Maintained by the R Development Core Team and with an active and growing community, it provides various statistical and graphical creation capabilities available under most operating systems, and is extensible with numerous packages available.

[1] https://www.wireshark.org/docs/wsug_html_chunked
[2] https://www.wireshark.org/docs/man-pages/tshark.html
[3] http://www.r-project.org/

5.5 C++

5.6 SQLite3

5.7 MongoDB/MySQL

References