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Communication

Simulation and Analysis of Cyber-Attack on Modbus Protocol for Smart Grids in Virtual Environment

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Abstract: Smart grid capabilities have grown significantly in recent years. The smart grid provides advanced real-time handling of faults, advanced automatic control for efficient electricity transmission, monitoring and collection of the electrical system's capacity, and communication for information sharing. Unfortunately, its exposure to public networks makes it increasingly vulnerable to privacy breaches, vulnerabilities, and cyber-attacks. Cyber security threats and vulnerabilities in smart grid networks have become a primary concern that needs to be addressed before deploying a smart grid. Furthermore, the wide range of protocols increases the attack surface of a smart grid. This study focuses on the vulnerability of Modbus, which is regarded as one of the most prevalent protocols in smart grid communication networks. This paper presents preliminary findings of analyzing cyber-attacks against the Modbus protocol using a virtual testbed to investigate its effects on the smart grid network protocol. The concept incorporates an emulated Modbus/TCP network environment built from open-source software components that imitate fundamental industrial control features of the smart grid. Finally, we analyze the cycle of a cyber-attack leading through Reconnaissance to a DoS attack on the Modbus/TCP protocol and propose improvements to the test bed for protocol attack detection and mitigation.

Keywords: smart grid (SG); communication protocols; Modbus; virtual testbed; cyber-attacks; and security vulnerabilities

1. Introduction

Smart Grid is a modern paradigm that has replaced the traditional electric grid in the energy sector. The concept of a smart grid system, as depicted in Figure 1, is the heterogeneous interconnection of dependent domains such as energy production, transmission, and distribution. The smart grid can harness programmable devices and networks to ensure two-way communication between the utility and the grid and between the utility and the consumers. Smart grids are highly automated and widely dispersed systems with advanced features such as real-time control, increased operational efficiency, grid resilience, and increased integration of renewable technology. An important impact of these features is the capability to minimize carbon footprint.

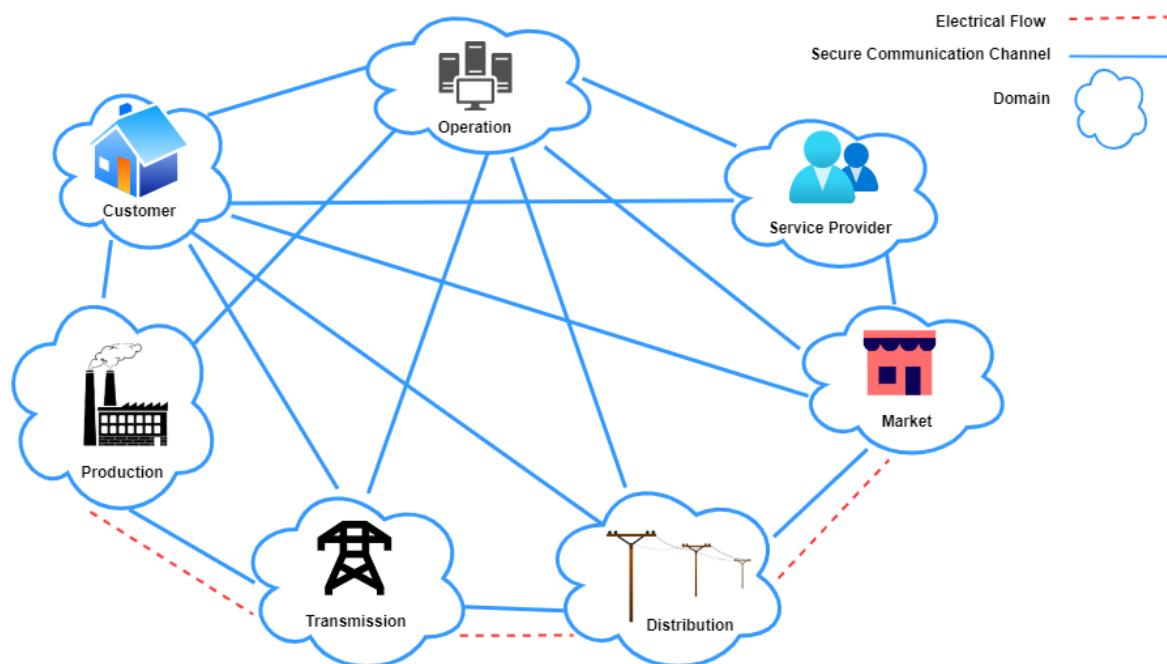


Figure 1. Smart Grid's conceptual model [1].

Smart grids combine disparate communication networks, such as those for the Internet of Things (IoT), industrial devices, wireless components, and Wireless Sensor Networks (WSN). Unfortunately, these protocols can be susceptible to various security threats. In smart grid architectures, these vulnerable protocols are typically connected to long-haul networks, such as the Internet, that expose them to malicious attackers. As a result, they pose serious security risks [2]. Network vulnerabilities could significantly impact private citizens and businesses, particularly if attackers target vital infrastructure like power plants, water distribution networks, and rail networks. Therefore, the government, businesses, and academia focus on securing smart grids.

Modbus is one of the most prominent network protocols found in smart grids. Traditional Modbus protocol cannot withstand cyberattacks as it lacks security and encryption. Information Technology (IT) and Operational Technology (OT) have seen exponential growth in security vulnerabilities for common network and SG technologies in recent years. These vulnerabilities are listed in the National Vulnerability Database (NVD) [3]. However, any vulnerability in the Modbus communication systems can affect the whole SG network.

To delve into any security research for such an Industrial Control System (ICS), particularly in the SG system, the testbed plays a pivotal role in modeling various cyber-physical system components that allow testing for security vulnerabilities and efficiency before the system is deployed [4]. Vulnerability analysis of the protocol based on testbed can mitigate the security risk *before* deployment and save money and possibly (and most importantly) lives.

This paper's contributions are as follows. First, we explore designing and developing a test bed in a virtual environment to simulate the smart grid system by mimicking the network between server and client. Second, we exploit the network vulnerabilities of Modbus/TCP by launching the Reconnaissance and DoS attacks followed by the attack cycle to monitor the effects of the system. We use Metasploit to simulate the attack on a simple test bed. We focus on Modbus and TCP protocols because they are two of the most widely used network protocols in smart grids. With this method, we analyze the results of the actions taken to compromise the smart grid's security. The findings of our study will be helpful for cyber forensics investigations into the Modbus protocol in the virtual testbed for the smart grid and projections for the future by overcoming the limitations.

In particular, the rest of this paper is organized as follows: Section 2 discusses the background literature. Section 3 outlined the Modbus/TCP protocol overview. Section 4 provides the experimental

setup, followed by section 5 with the experimental results and analysis. The limitation and future work appears in section 6. Finally, section 7 concludes this study.

2. Related Works

Recent, pertinent research on security on Modbus in the smart grid has been studied in depth. We attempted to categorize our findings in this work from many research viewpoints to explore the Modbus cyber attacks in the SG. The most relevant work to our research is in the categories of Modbus cyber-attacks, various detection techniques, including Intrusion Detection Techniques that can be deployed upon Modbus, and testbed-based countermeasures to prevent cyber attacks on Modbus.

Modbus cyber attacks. A complete theoretical analysis of the multiple cyber-attacks against the Modbus protocol was published in [5]. The attacks' threat categories, targets, and control system asset impacts are summarized. The attack taxonomies define Modbus's control system and network security risks, making formal risk analysis easier. In [6], the authors conducted four distinct cyber-attacks on the Modbus protocol to compile pertinent data that machine learning algorithms may use. The authors identified intrusions that share traits with well-known assaults. They employed neural networks and decision trees to categorize the traffic produced by this simulated environment. Another review [7] presents different attack taxonomy as an intrusion on various protocols of the SG communication protocol with a recommendation of mitigation technique. The authors in [8] list 17 assaults on SCADA control systems. Attacks fall into four categories: reconnaissance, response and measurement injection, command injection, and denial of service.

Detection Techniques. T. Morris et al. published Modbus-related rules in [9], and popular signature-based IDS like Snort and Suricata can use these. Researchers developed the rule set for intrusion detection systems during a vulnerability study of the Modbus/TCP and Modbus over Serial Line networks. A Modbus/TCP fuzzer called MTF was designed and implemented by Voyiatz et al. [10]. Reconnaissance is a step in the MTF testing process that helps map the capabilities of the tested device and modify the attack vectors. In [11], the authors describe a series of experiments demonstrating the effectiveness of a signature-based Snort threshold module and an anomaly-based change detection method for spotting Modbus flooding attacks. In the research [12], the authors analyzed 37 cases and then looked at the Implementation and Detection of Modbus in the smart grid paradigm. The IDPS systems are an additional line of defense that strengthens cryptographic operations by promptly identifying and preventing potential security breaches. The paper's authors [13] proposed a two-fold IDS. They started by researching and improving the cyber-attacks offered by the Smod pen-testing program. The second step is introducing an intrusion detection system (IDS) based on anomalies that might spot intrusions that result in Modbus/TCP denial of service (DoS). The authors in [14] suggested an intrusion detection technique that uses a honeypot for the Modbus TCP protocol. The proposed solution uses an unsupervised clustering technique based on similarities between log sequences and cluster attacking patterns.

Testbed Based Solution. A CPS testbed called [15] was used to develop the Modbus/TCP Attack-Tree model to exploit several assaults. This model includes attacks such as replay, man-in-the-middle, denial-of-service, and reconnaissance. With the integration of assault time, detection time, and plant-hazard generating time, this serves as a formal risk assessment model. The approach in [16] is the development of a test bed based on the Modbus Protocol of nuclear power plants for cybernetic attacks analysis. The concept incorporates a simulated Modbus/TCP network environment with fundamental industrial control features created using free and open-source software. The paper [17] presented a virtual testbed for implementing a Man-in-The-Middle (MITM) attack on the Modbus protocol to analyze Modbus vulnerabilities, practical limitations of modern smart grid systems, and relevant prevention measures. The authors of [4,18] conducted an in-depth analysis of the known and reported network vulnerabilities in the Modbus protocol. They reviewed numerous attempts at exploiting such network vulnerabilities in creating the virtual test bed. Since the main concept of the most deployed testbed is a cyber-physical system that incorporates many simulation tools, Typhoon

HIL, unfortunately, lacks many important features; for example, TYfoon is not worried about the network as to why it has no packet analyzed. This is one of the crucial aspects of choosing a VM with all the necessary tools to assist in conducting any network security-related study or analysis.

Alternative Countermeasures. An alternative method is [19], which developed the MODLSTM Neural Network architecture, comprising input preprocessing, feature recording, and traffic classification to identify Modbus-related DoS assaults. A case study presents various countermeasures that can enhance security for the Modbus/TCP protocol in SCADA systems by studying and testing the current security countermeasures specific to SCADA systems [20]. A model for organizing information security in Modbus TCP was presented in [21]. The paper [22] surveys detection and mitigation techniques against denial-of-service (DoS) attacks on the Modbus protocol in the smart grid. It evaluates the effectiveness of the current approach and outlines the prospects for future research. Different machine learning-based anomaly detection techniques were applied to an industrial Modbus/TCP data set to detect fraudulent traffic in a synthetically generated Modbus/TCP communication data set in a hypothetical industrial setting. In [23], S. Anton et al. utilized and evaluated various machine learning classification techniques for identifying Modbus threats. An approach has been proposed to cluster cyber attacks targeting Modbus-enabled SCADA and ICS devices. The network telescope sensors have been deployed to empirically evaluate the approach on one month of real network data. Fachkha. et al. [24] presents a thorough investigation to determine cyber scanning activities into SCADA Modbus communication.

To our knowledge, there has not been enough published research on deploying a virtual environment as a testbed to carry out cyber analysis on any crucial protocol of the SG system and the literature on simulating testbed; nobody is concerned about the network security. After digging deeper into the recent studies on Modbus security-related works, we focused on conducting the cyber investigation on Modbus/TCP in a virtual testbed. Regarding network architecture and security concerns, our work significantly differs from others, which could open a new avenue to research in this domain.

The following aspects of a virtual machine (VM) have facilitated our work to serve as a promising virtual testbed for Modbus/TCP that imitates the real-time scenario.

- VM facilitates the real protocol setup into the Network architecture according to the experimental requirements. This setup has many tools that allow us immediate visualization and automation to carry on large-scale experiments.
- VMs allow automated experimental setup given dynamic parameters.
- VMs allow analysis both inside the VM as well as outside. The attacker can compromise analysis tools inside the VM but allow more specific and detailed analysis. Analysis outside the VM protects the analysis tools from the attacker. Can reference existing general-purpose black box tools.
- VMs isolate the network from dangerous attacks by simulating the network instead of sending the packets over the actual network.
- The VM has many tools available to do analysis, compared to (examples: packet analyzers, process image analyzers, memory analyzers, etc.).
- VM can be remotely operated, making the experiments far more flexible.

This testbed is developed to resolve the following security issues in Modbus protocol research.

- Establish a communication network between the Modbus components like the real-time testbed
- Analysis of the level of vulnerability of Modbus/TCP protocol
- Estimating the security impact on the system due to this exploitation
- Discussing the defense mechanism

3. Modbus/TCP Protocol

Modbus was initially designed for communication in industrial control systems and was developed more than 40 years ago by PLC manufacturer Modicon™, which is now Schneider Electric™. It continues to be widely used for SCADA/ICS applications such as smart grid systems. Its use is widespread for several reasons: it is an open standard, simple to apply, and practically all commercial automation equipment comes with implementing it. Modbus is available in three formats: ASCII, RTU, and TCP. Hexadecimal is utilized in the first one to encode messages. Despite being slow, it is excellent for radio links and phone conversations. The Modbus TCP/IP protocol is frequently utilized in industrial automation control systems. These control systems are crucial in industrial operations such as regulating refineries and gas turbines. It is simple to use and allows the transmission of unencrypted raw data without encryption or authentication[25]. This factor, in particular, led to the selection of Modbus/TCP. But years ago, the protocol was developed without any security consideration. In the second, binary-coded messages are transmitted over RS232. Figure 2 illustrates the stacks for the Modbus protocol application layer.

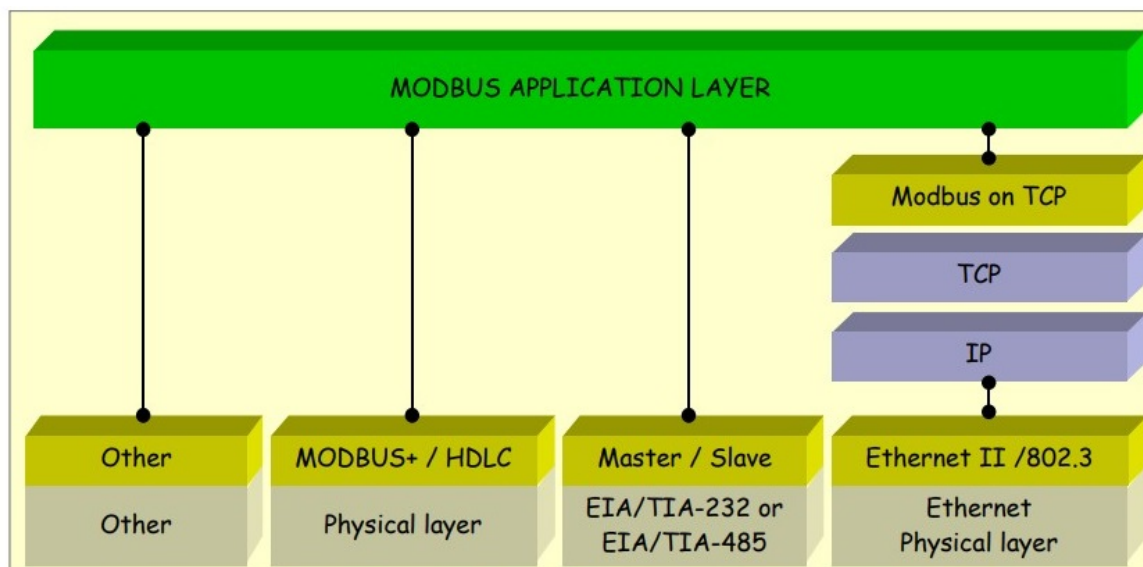


Figure 2. Stacks for the application layer: Modbus [26].

Modbus is a master-slave protocol that enables one master, also known as a remote terminal unit (RTU) or master terminal unit (MTU), and numerous slave devices, including sensors, drivers, and PLCs, to communicate with one another and share instructions in a SCADA system[9]. This OSI model level seven application layer messaging protocol enables client/server communication between devices connected to various buses or networks [27]. A master/slave architecture is employed in Modbus to communicate with multi-drop devices. The Modbus TCP protocol enables communication between a master and its slaves in a LAN-based Modbus network and between multiple masters in IP-connected Modbus networks (each with multiple slaves). By allowing a slave to communicate concurrently with many masters and a master to have several transactions open simultaneously, Modbus TCP expands the capabilities of its serial counterpart [5]. Modbus/TCP master-slave, in other words, client-server communication, is illustrated in Figure 3.

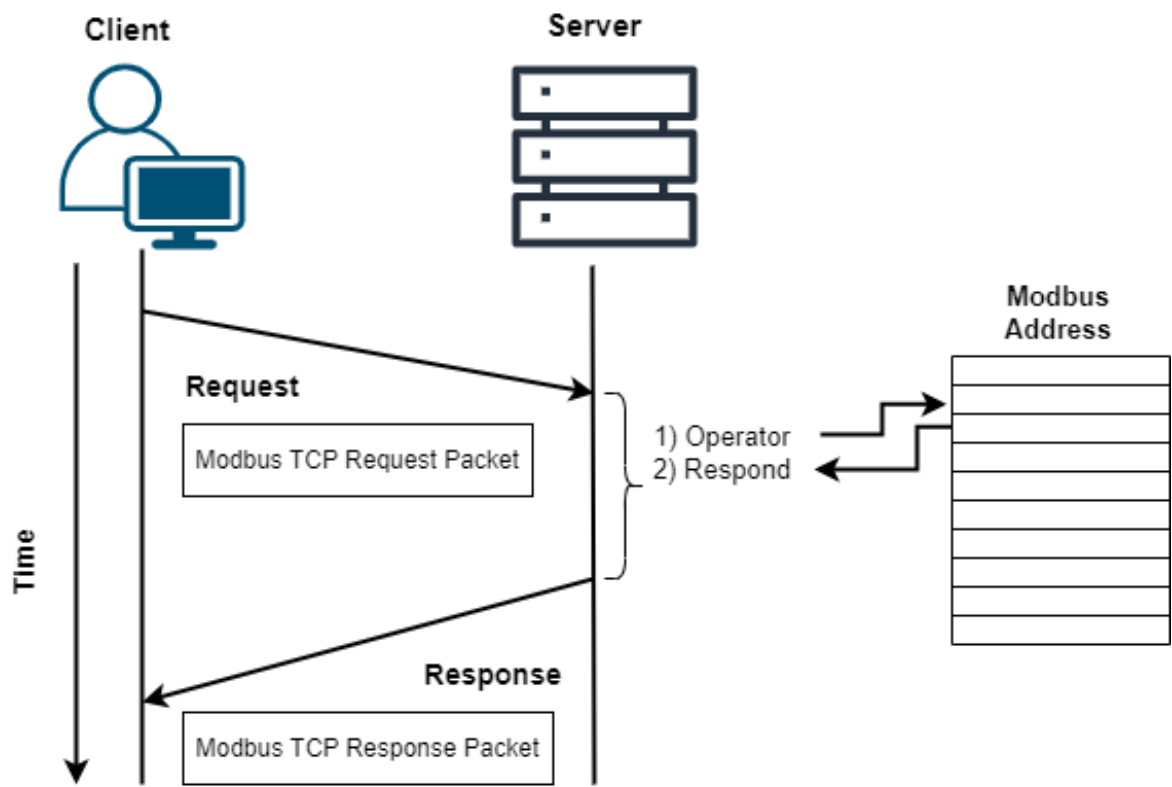


Figure 3. Modbus/TCP client-server communication.

4. Experimental Setup

In this section, we outline the specifications when developing the suggested testbed and discuss the principle that was the foundation for validating our design. The simulation strategy is software-based, and this virtual testbed component is described and discussed in detail below.

This paper presents a real-time virtual test bed, as shown in Figure 4. Our testbed has been developed in a virtual environment integrating the Modbus server, client, and attacker.

We employed a virtual machine to run the Modbus Master Simulator for the master (VM2). First, we create a simulated Modbus environment and test the connectivity between the server and the client. The emulated Modbus Master can access and control those Modbus Slaves through the Modbus Gateway as long as virtual machines 1 and 2 (VM1 and VM2) are connected. Numerous Modbus Slave Simulators are available. ModbusPal, a Java-based Modbus Slave emulator that works with any operating system that supports Java, is used in this project [28]. This software provides a graphical user interface; therefore, creating many Modbus slaves is simple.

We execute ModbusPal on Modbus Slave on one virtual machine (VM1) (which accepts TCP connections on port 502). It emulates a Modbus Gateway with the virtual machine’s IP address while running ModbusPal on just one virtual machine (VM1) (accepts TCP connections on port 502). Each Slave we build using ModbusPal is identifiable by its Unit ID (ranging from 1 to 247).

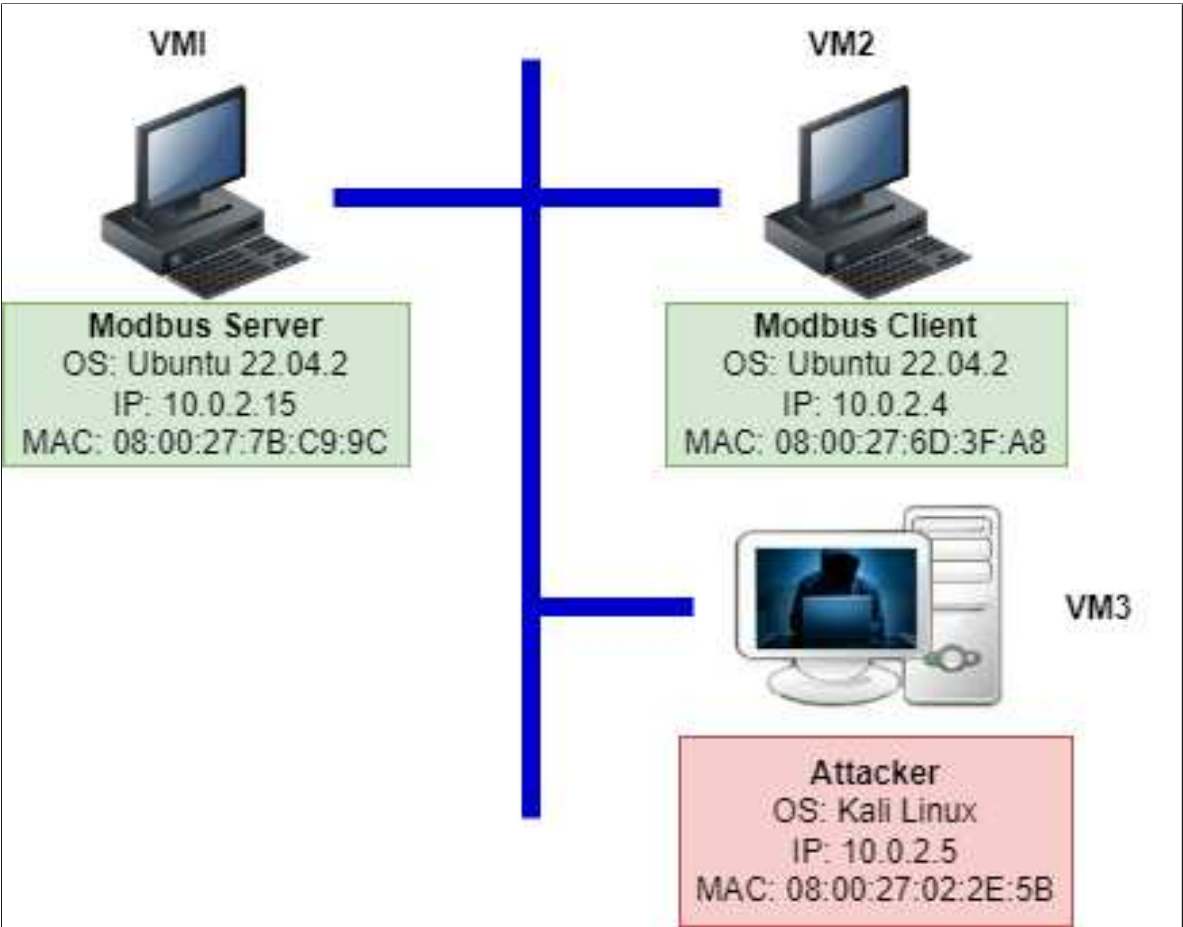


Figure 4. The Virtual Testbed Setup.

Modbus Master and Slave Communication Environment Setup

Modbus is a master-slave protocol where they communicate with each other through IP addresses [11]. Therefore, attackers can use software such as Shodan [29] to find and remotely target Modbus installations for Internet-connected devices. Additionally, because various PLC manufacturers integrate the protocol into their devices as an option, and those devices respond to external commands without requiring authentication, they are vulnerable to injection attacks [9].

The Modbus packet has been captured to ensure the communication between the master and slave employing wireshark in Figure 5.

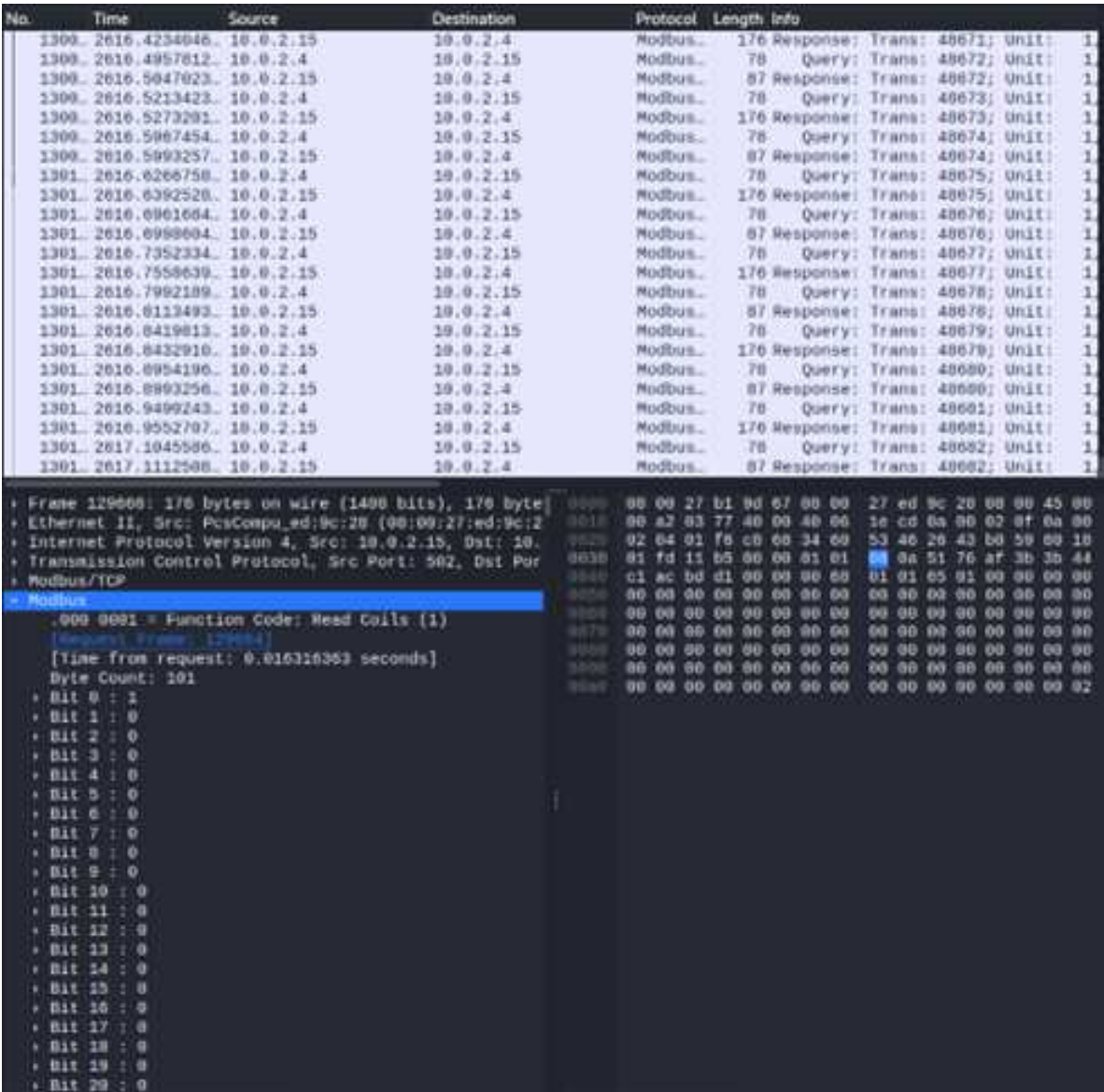


Figure 5. Wireshark Captured Modbus Packets.

5. Results and Analysis

The cyberattack scenario on the Modbus protocol is shown in Figure 6. The malicious hackers or attackers frequently follow four stages of the attack cycle to attack and acquire control of the system through the Modbus protocol. Those stages are *unauthorized access*, *reconnaissance*, *scanning*, and *exploitation*.

Unauthorized Access: In the first step, the attacker can get unauthorized access to the system by several means, such as manipulating any user login, temping user login, or installing covert and undetected software.

Reconnaissance Attacks & System Scanning: After obtaining unauthorized access to the system, reconnaissance is the second phase in which the attacker learns everything about the target. In the third stage, scanning, the attacker hunts for system network weaknesses. When an attacker targets a victim’s system to learn about its weaknesses, this is known as a reconnaissance attack. These activities strive to discover the newly opened ports and learn about the services provided by each port, as well as their shortcomings. During the exploitation phase, the attacker seeks to compromise and gain complete control of the target by performing a wide range of potential cyber-attacks. Once the attacker

starts exploiting the victim, the fourth step begins. In this virtual testbed, the Modbus/TCP has been the target of automated cyber attacks scripted in a scripting language.

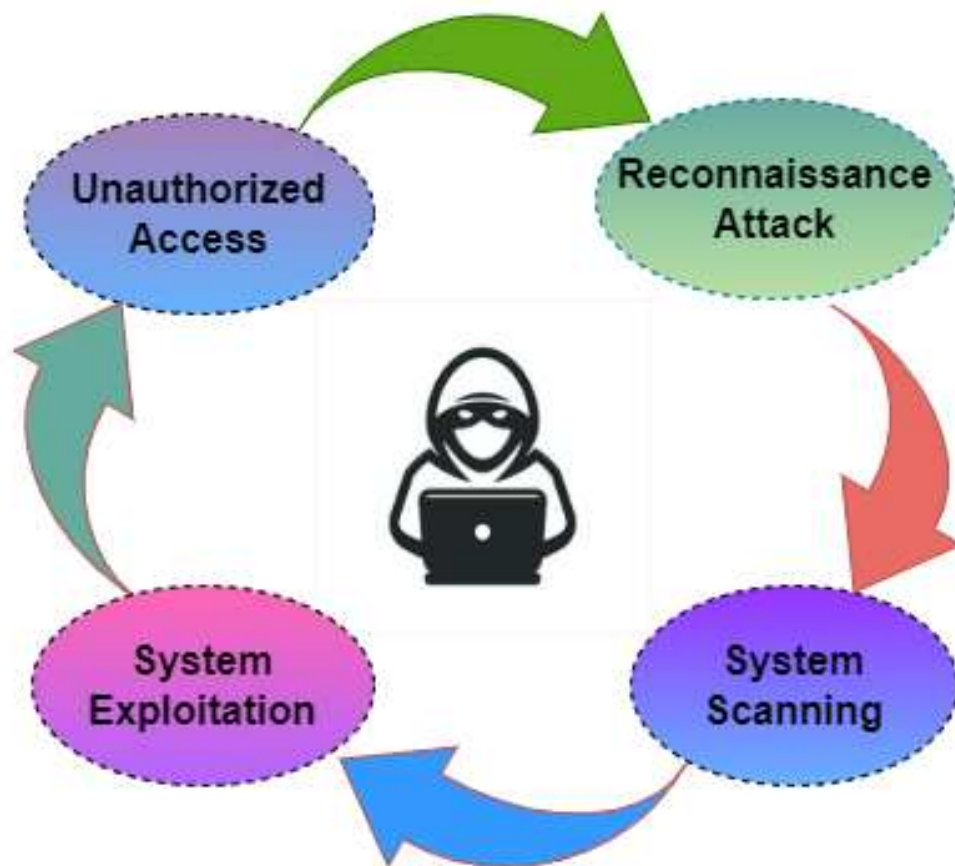


Figure 6. Attacking cycle followed by attackers to exploit the system.

The two components of this analysis to plan and carry out a reconnaissance attack on Modbus protocol are as follows:

- 1. Performing a network scan (IP address & MAC address) to discover our virtual network's IP addresses, MAC addresses, and open ports using NMAP.
- 2. To determine the registers, coils, and function codes available in the Modbus protocol using S-MOD.

In a reconnaissance assault, by using 'nmap', the attacker can only get to know the data and cannot alter or block packets, as shown in Figure 7 and Figure 8.

```
(kali@kali)-[~]
$ sudo nmap -sn 10.0.2.5/24
Starting Nmap 7.92 ( https://nmap.org ) at 2023-03-22 02:01 EDT
Nmap scan report for 10.0.2.1
Host is up (0.00021s latency).
MAC Address: 52:54:00:12:35:00 (QEMU virtual NIC)
Nmap scan report for 10.0.2.2
Host is up (0.00017s latency).
MAC Address: 52:54:00:12:35:00 (QEMU virtual NIC)
Nmap scan report for 10.0.2.3
Host is up (0.00044s latency).
MAC Address: 08:00:27:11:FB:85 (Oracle VirtualBox virtual NIC)
Nmap scan report for 10.0.2.4
Host is up (0.00027s latency).
MAC Address: 08:00:27:6D:3F:A8 (Oracle VirtualBox virtual NIC)
Nmap scan report for 10.0.2.15
Host is up (0.00034s latency).
MAC Address: 08:00:27:7B:C9:9C (Oracle VirtualBox virtual NIC)
Nmap scan report for 10.0.2.5
Host is up.
Nmap done: 256 IP addresses (6 hosts up) scanned in 2.22 seconds
```

Figure 7. NMAP scanning from KALI VM.

```
(kali@kali)-[~]
$ sudo nmap -sT -p 0-10000 10.0.2.5/24
Starting Nmap 7.92 ( https://nmap.org ) at 2023-03-22 02:08 EDT
Nmap scan report for 10.0.2.1
Host is up (0.0011s latency).
Not shown: 10000 closed tcp ports (conn-refused)
PORT      STATE SERVICE
53/tcp    open  domain
MAC Address: 52:54:00:12:35:00 (QEMU virtual NIC)

Nmap scan report for 10.0.2.2
Host is up (0.0029s latency).
Not shown: 9997 filtered tcp ports (no-response)
PORT      STATE SERVICE
135/tcp   open  msrpc
445/tcp   open  microsoft-ds
7070/tcp  open  realserver
8000/tcp  open  http-alt
MAC Address: 52:54:00:12:35:00 (QEMU virtual NIC)

Nmap scan report for 10.0.2.3
Host is up (0.00089s latency).
All 10001 scanned ports on 10.0.2.3 are in ignored states.
Not shown: 10001 filtered tcp ports (proto-unreach)
MAC Address: 08:00:27:11:FB:85 (Oracle VirtualBox virtual NIC)

Nmap scan report for 10.0.2.4
Host is up (0.0013s latency).
All 10001 scanned ports on 10.0.2.4 are in ignored states.
Not shown: 10001 closed tcp ports (conn-refused)
MAC Address: 08:00:27:6D:3F:A8 (Oracle VirtualBox virtual NIC)

Nmap scan report for 10.0.2.15
Host is up (0.00061s latency).
Not shown: 9999 closed tcp ports (conn-refused)
PORT      STATE SERVICE
502/tcp   open  mbap
8080/tcp  open  http-proxy
MAC Address: 08:00:27:7B:C9:9C (Oracle VirtualBox virtual NIC)

Nmap scan report for 10.0.2.5
Host is up (0.00049s latency).
All 10001 scanned ports on 10.0.2.5 are in ignored states.
Not shown: 10001 closed tcp ports (conn-refused)

Nmap done: 256 IP addresses (6 hosts up) scanned in 96.05 seconds
```

Figure 8. NMAP Port scanning from KALI VM.

In the second attempt of reconnaissance assault, by using 'smod', the attacker is only able to observe registers, coils, and function codes that are available in the Modbus protocol as shown in both Figure 9 and Figure 10.

```

SMOD modbus(getfunc) >set RHOSTS 10.0.2.15
SMOD modbus(getfunc) >set UID 01
SMOD modbus(getfunc) >exploit
[+] Module Get Function Start
[+] Looking for supported function codes on 10.0.2.15
[+] Function Code 1(Read Coils) is supported.
[+] Function Code 2(Read Discrete Inputs) is supported.
[+] Function Code 3(Read Multiple Holding Registers) is supported.
[+] Function Code 4(Read Input Registers) is supported.
[+] Function Code 5(Write Single Coil) is supported.
[+] Function Code 6(Write Single Holding Register) is supported.
[+] Function Code 15(Write Multiple Coils) is supported.
[+] Function Code 16(Write Multiple Holding Registers) is supported.

```

Figure 9. Read the function code of Modbus protocol.

```

SMOD modbus(readCoils) >set RHOSTS 10.0.2.15
SMOD modbus(readCoils) >set UID 01
SMOD modbus(readCoils) >exploit
[+] Module Read Coils Function Start
[+] Connecting to 10.0.2.15
[+] Response is :
###[ ModbusADU ]###
  transId  = 0x103
  protoId  = 0x0
  len      = 0x4
  unitId   = 0x1
###[ Read Coils Answer ]###
  funcCode = 0x1
  byteCount = 1L
  coilStatus= [4]

SMOD modbus(readHoldingRegister) >set RHOSTS 10.0.2.15
SMOD modbus(readHoldingRegister) >set Quantity 0x0008
SMOD modbus(readHoldingRegister) >set StartAddr 0x0000
SMOD modbus(readHoldingRegister) >set UID 01
SMOD modbus(readHoldingRegister) >exploit
[+] Module Read Holding Registers Start
[+] Connecting to 10.0.2.15
[+] Response is :
###[ ModbusADU ]###
  transId  = 0x2
  protoId  = 0x0
  len      = 0x13
  unitId   = 0x1
###[ Read Holding Registers Answer ]###
  funcCode = 0x3
  byteCount = 16L
  registerVal= [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]

```

Figure 10. Reading Holding Register and Coil Status Values of the Modbus protocol.

It is evident that function codes 1 through 4 allow the attacker to construct the reconnaissance attack. Thus, it is possible to access the network, allowing the attacker to see the resource data. However, in a reconnaissance attack, the function codes 5 through 16 cannot be used by the attacker to alter the values of registers or coils (because of write type data).

System Exploitation: The control center will receive delayed information from IEDs during the DoS attack. If the DoS attack blocks the measurement, the control center will not have an accurate image of the system's status. Smart grid applications in the control center that rely on IED data will malfunction.

In our denial-of-service attacks, the *LAND assault* and *SYN Flood attacks* were developed in Part 1.

The LAND and SYN Flood assaults are two separate kinds of Denial of Service (DoS) attacks that aim to block access to a system by authorized users. Several attack strategies and weaknesses are used in each situation, which makes them distinct. In Part 1 of the DoS attack, we employed the LAND attack by the following command in the terminal of the Kali Linux machine.

Figure 11. illustrates the outcome of the LAND assault in Wireshark. When the LAND attack was successful, we discovered that the PLC's IP address was faked and that both the source and destination showed the same IP address, as shown in Figure 2. Data transfer uses the TCP protocol and the 502 receiving port. Additionally, it is demonstrated that repetitive network packets are sent to establish a connection and cause a system crash and denial of service to legitimate users.

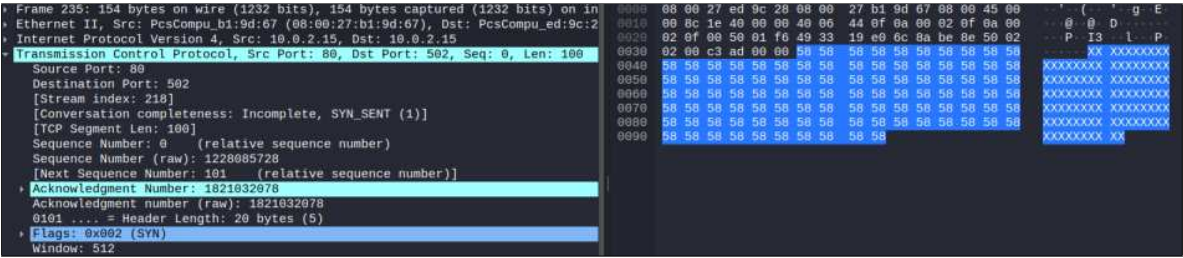


Figure 11. Packet captured in Wireshark after LAND command.

In Part 2 of the DoS attack, we performed the SYN flood attack by writing the following command in the terminal of the Kali Linux machine.

TCP SYN flood attack tactic was used to flood the Modbus Master to test the delay-sensitive nature of Modbus TCP [30]. A TCP SYN Flood Attack uses the TCP three-way connection handshake method to create a dependable session between a sender and a receiver [31]. The Modbus Master is subjected to a TCP SYN flood attack, which floods it with TCP 0 connection requests from possible Modbus clients with forged source IP addresses and arbitrary destination TCP ports, according to Breaker Status. The Modbus master was targeted by fake TCP SYN requests sent using the Hping tool [32].

Figure 12. shows the data collected in Wireshark after a successful SYN flood attack by initializing the target IP address and port number.

4101...	8.733636310	10.0.2.5	10.0.2.15	TCP	54 1361 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733648360	10.0.2.5	10.0.2.15	TCP	54 1362 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733660238	10.0.2.5	10.0.2.15	TCP	54 1363 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733671570	10.0.2.5	10.0.2.15	TCP	54 1364 → 502 [RST] Seq=1 Win=0 Len=0

Figure 12. The captured packet in Wireshark after SYN flood attack.

Using Metasploit to Perform a DoS Attack

In reality, Metasploit is a specific type of DoS attack in which the attacker takes advantage of flaws in the target system to make it crash or stop working. Penetration testing and exploitation are the primary uses of this Metasploit attack. It is distinguished by a unique traffic pattern shown in Figure 13.

No.	Time	Source	Destination	Protocol	Length	Info
4101...	8.733636310	10.0.2.5	10.0.2.15	TCP	54	1361 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733648360	10.0.2.5	10.0.2.15	TCP	54	1362 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733660238	10.0.2.5	10.0.2.15	TCP	54	1363 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733671570	10.0.2.5	10.0.2.15	TCP	54	1364 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733756205	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1365 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.733772757	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1366 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.733829391	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1367 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.733901562	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1368 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.733966290	10.0.2.15	10.0.2.5	TCP	60	502 → 1365 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.733966388	10.0.2.15	10.0.2.5	TCP	60	502 → 1366 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.733966461	10.0.2.15	10.0.2.5	TCP	60	502 → 1367 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.733973599	10.0.2.5	10.0.2.15	TCP	54	1365 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733985713	10.0.2.5	10.0.2.15	TCP	54	1366 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.733997661	10.0.2.5	10.0.2.15	TCP	54	1367 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.734019946	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1369 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.734037408	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1370 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.734092598	10.0.2.15	10.0.2.5	TCP	60	502 → 1368 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.734098202	10.0.2.5	10.0.2.15	TCP	54	1368 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.734167043	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1371 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.734182884	10.0.2.5	10.0.2.15	TCP	54	[TCP Port numbers reused] 1372 → 502 [SYN] Seq=0 Win=512 Len=0
4101...	8.734225249	10.0.2.15	10.0.2.5	TCP	60	502 → 1369 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.734225331	10.0.2.15	10.0.2.5	TCP	60	502 → 1370 [SYN, ACK] Seq=0 Ack=1 Win=64240 Len=0 MSS=1460
4101...	8.734230396	10.0.2.5	10.0.2.15	TCP	54	1369 → 502 [RST] Seq=1 Win=0 Len=0
4101...	8.734241960	10.0.2.5	10.0.2.15	TCP	54	1370 → 502 [RST] Seq=1 Win=0 Len=0

Figure 13. The captured packet in Wireshark after Metasploit attack.

We carried out the LAND attack in Part 1 and then the SYN flood attack in Part 2. They both represent distinct Denial of Service (DoS) attacks. The LAND attack involves the attacker spoofing the victim's IP address as the packet source, sending packets to the victim's system with the SYN flag set, and setting the destination port to the same port as the source port. As a result, the victim's system constantly tries to connect with itself, using up resources and possibly resulting in system

crashes. Furthermore, the SYN flood attack causes the target system to allocate resources for each connection attempt. It keeps the resources busy until they time out, which causes the system to become unresponsive or crash. The attacker floods the server with numerous SYN packets with bogus IP addresses, making it challenging for the server to discriminate between real and phony connection requests. Another observation is that the SYN flood attack executes much more quickly than the LAND attack. The main distinction between a LAND assault and a SYN flood attack is that the former overloads the server with connection requests as traffic. At the same time, the latter uses a flaw in the victim's operating system by delivering packets with a fake IP address. Lastly, the experiment has been accomplished, proving the virtual simulation is good enough not to hamper any hardware in the loop.

6. Limitation and Future Work

Even though our strategy entails creating a test bed replicating a real-time smart grid system and studying how the cyberattack on Modbus affects it, it requires adding more hardware to the loop to identify the attack at a different network layer. Another limitation is that it is not simulating full devices but only simulating the mathematical properties of the respective devices. So, the problem is scalability, as the VM is heavyweight. If I have an SG with many devices and I spawn the VM for each device, my host will eventually be unable to simulate all the VMs. It can be overcome by simulating multiple devices within a single guest VM or having multiple network hosts running multiple guest VMs. The assessment was only done on a limited scale; it must also be verified on a larger size. We intend to extend our work performing with more potential cyber-attacks, such as man-in-the-middle (MiTM) and false data injection (FDI) on different protocols, for instance, on WiMax, DNP3 in the future, so that we may look into the system how it responds to an attack or after the attack has occurred. To validate, we can use some machine learning tools to verify our work in the following stage.

7. Conclusions

This paper highlights the significance of employing a virtual environment for examining the popular SG protocol, the Modbus, by identifying its vulnerabilities, exploiting them to launch different potential cyber-attacks, and analyzing their influence on the SG system. Case studies demonstrate that the Modbus protocol could be more trusting, as it lacks access control lists and a trusted domain. The successful implementation has overcome the challenge of integrating hardware in the loop, vital in developing any CPS system, such as the SG system. The effective deployment of the VM in the analysis can be considered a pivotal contribution in this domain. One of the important findings during the experiment was that none of the packets entered our campus network. This indicates that the virtual testbed can be considered a secure cyber-security-related research and analysis platform. Aggregating or visualizing data after running the experiment overnight is the nicest aspect of the virtual environmental setup. We analyzed how the Reconnaissance and DoS attacks can severely affect the SG system's operation and stability. With the Reconnaissance attack, the attacker can learn the system data and control commands into numerous smart grid applications. As a result, the system's security and stability are compromised, allowing any attacker who gains knowledge of the IP address of the Modbus master to target it for launching any malicious attack like DoS to cripple the entire system.

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