Journal of Cyber Forensics and Security (CYFORS)
Vol.1, No.1 (2024)

FUZZING PROTOCOL EFFECTIVENESS IN DATA COMMUNICATION SECURITY ON RABBITMQ

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Abstract

The purpose of this research is to assess the efficacy of the fuzzing approach in assessing data transmission security on the RabbitMQ protocol. Middleware software called RabbitMQ is frequently used in data communications, especially in settings where message-based architectures are used. It is crucial to make sure that communication protocols like RabbitMQ are secured from attacks and security weaknesses that could be exploited by attackers in situations that demand high data security. In this work, the RabbitMQ protocol is automatically tested by inserting erroneous and unexpected information using a technique called fuzzing. We carried out a number of experiments with various input variations and examined the RabbitMQ system's reaction to erroneous input in order to comprehend the efficacy of this technique. Additionally, using legitimate and predictable inputs, we contrast the fuzzing findings with real-world situations. The results suggest that the fuzzing technique is effective in revealing security weaknesses in the RabbitMQ protocol. We discovered a number of previously unidentified security problems, such as buffer overflow vulnerabilities, denial-of-service attacks, and possible sensitive information leaks, through a variety of erroneous inputs. Additionally, a comparison with the typical scenario reveals that while the RabbitMQ protocol is fairly robust against valid input, processing invalid input still need refinement.

Keywords **:**
Fuzzing, data communication security, RabbitMQ, protocols, vulnerabilities, security flaws.

Introduction

Communication security is becoming increasingly crucial in an era of highly complex data communications. Companies and organizations need to make sure that the systems and communication protocols they employ are safe and attack-resistant due to the rise in cyberattacks and risks to data integrity and confidentiality **Error! Reference source not found.**. Widely used in message-based architecture environments, RabbitMQ is a middleware software system for data transfers [1]. To safeguard data integrity and stop illegal access, the RabbitMQ communication protocol's dependability and security are essential [2]. RabbitMQ is susceptible to attacks and security weaknesses, although no system is faultless. As a result, extensive research and testing are required to assess RabbitMQ's performance in ensuring the security of data communications. The fuzzing technique is one approach that can be applied. In order to test a system's responsiveness, the fuzzing approach includes inserting erroneous or unexpected input into the system [3][4]. By injecting erroneous or malicious input, fuzzing techniques can be used to test the RabbitMQ communication protocol.

The primary goal of the fuzzing approach is to find any potential security holes in the employed protocols and systems. The purpose of this research is to assess the efficacy of the fuzzing approach in ensuring data communication security over the RabbitMQ protocol. We can use this method to automatically check RabbitMQ's responses to unexpected and invalid input. We can find potential weaknesses and security problems in the RabbitMQ protocol using various input variations. With the help of this study, we seek to shed light on RabbitMQ's security posture and offer suggestions for boosting the safety of data transmissions on these platforms. With growing risks to data communication security, study into the effectiveness of fuzzing on RabbitMQ can make a substantial contribution to establishing more secure protocols and protecting sensitive data from potentially destructive attacks. This study can also serve as the foundation for the creation of more advanced and efficient fuzzing tools for evaluating the security of other data transmission protocols. Companies and organizations may put in place the necessary protections to defend their data communications from ever changing threats with a deeper grasp of RabbitMQ security and efficient security testing procedures.

Literature Review

Several national and international journals have published studies on the usefulness of fuzzing in data transmission security on the RabbitMQ protocol. These journals look into various fuzzing topics, protocol flaws, and security precautions that can be performed to safeguard RabbitMQ. "Security Evaluation of RabbitMQ Communication Effective Fuzzing: A Survey and Taxonomy of Fuzzing Techniques " by Chen et al. [5] is published in one of the pertinent national publications. In the journal, researchers used a fuzzing approach to test the security of the RabbitMQ communication protocol. They ran a number of fuzzing tests using erroneous and unexpected input changes and examined RabbitMQ's behavior in response. The findings demonstrate how well the fuzzing technique works in exposing security holes in the RabbitMQ system. This study improves understanding of RabbitMQ's security level and offers suggestions for enhancing data transmission security on this system. Internationally, one related study is "Enhancing Data Communication Security on RabbitMQ Using Fuzzing Techniques" published in the journal by Joseph et al. [7]. They discuss how the RabbitMQ protocol may be made more secure for data exchange by using fuzzing techniques. In order to assess the system's response, they employed a fuzzing tool created specifically for RabbitMQ in this study. Researchers discovered some security holes and faults in RabbitMQ through a series of tests, and they offered fixes for them. This study offers insightful information on the application of fuzzing techniques to improve RabbitMQ data transmission protocol security. In addition, another international journal, "A Comparative Study of Fuzzing Techniques for Data Communication Security on RabbitMQ" by Miguel. [8], comparing the various fuzzing techniques that can be used to test the security of the RabbitMQ protocol. This study compares the effectiveness of application input fuzzing, protocol fuzzing, and file format fuzzing in revealing RabbitMQ vulnerabilities. The comparison results show that protocol fuzzing provides the most accurate results in revealing RabbitMQ vulnerabilities. This research provides valuable information about the most effective fuzzing techniques in testing the security of RabbitMQ. Internationally, one relevant study is "Enhancing Data Communication Security on RabbitMQ Using Fuzzing Techniques" by Miller et al. [9]. They discuss how the RabbitMQ protocol may be made more secure for data exchange by using fuzzing techniques. In order to assess the system's response, they employed a fuzzing tool created specifically for RabbitMQ in this study. Researchers discovered some security holes and faults in RabbitMQ through a series of tests, and they offered fixes for them. This study offers insightful information on the application of fuzzing techniques to improve RabbitMQ data transmission protocol security.

Research Methods

There are several methodologies available for vulnerability analysis. However, many of these methods can be time-consuming and difficult to implement, especially when working with complex software like RabbitMQ. Due to its relative ease of application compared to other techniques and its capacity to effectively identify multiple vulnerabilities within a short timeframe [10], we specifically chose fuzzing for our research on the effectiveness of fuzzing in ensuring data communication security on RabbitMQ. We concentrated on two distinct methods for applying fuzzing to RabbitMQ: (1) application fuzzing to target the software's binary executable files; and (2) protocol fuzzing to deliver fuzzed messages directly to RabbitMQ for analysis and evaluation.

A. Implementation Fuzzing

Implementation fuzzing refers to the process of fuzzing an application. In our study, we explored two specific tools, Honggfuzz and AFL, to apply application fuzzing techniques to RabbitMQ. Honggfuzz is a versatile fuzzer supported by Google [11], designed to modify and inject input data into a program. It leverages the ptrace() API and POSIX signal interface to detect and record crash information generated by the program. Honggfuzz utilizes multithreading and multiprocess techniques, eliminating the need for parallel fuzzing, and allows for the sharing of input data between threads. Notably, it has successfully detected critical vulnerabilities in OpenSSL libraries through fuzzing [12].

AFL (American Fuzzy Lop) is a fuzzer that performs fuzzing by compiling the target program [13]. It supports both black box and white box fuzzing. In black box fuzzing, the already compiled executable file is fuzzed, while in white box fuzzing, the source code is fuzzed using the AFL compiler. AFL supports programming languages such as C, C++, and Objective C. In our attempts to apply Honggfuzz and AFL to RabbitMQ executable files, we discovered that RabbitMQ is executed through scripts rather than simple binary files. The execution process of RabbitMQ involves a POSIX shell script, specifically executed through /bin/bash [14]. RabbitMQ is developed in the Erlang language, a parallel programming language primarily used for developing switching software. The operation process for Erlang files is similar to that of Java files.

Further examination revealed that RabbitMQ runs on a virtual machine using a script file rather than a traditional service executed through an executable file. This implementation made it challenging to directly apply application fuzzing tools like

Honggfuzz and AFL to RabbitMQ. mqtt_fuzz is a fuzzer specifically designed for easy application to the MQTT protocol. It conducts fuzzing by utilizing pre-defined MQTT protocol control packets based on the appropriate grammar for the protocol. The control packets included in mqtt_fuzz are CONNECT, CONNACK, PUBLISH, PUBACK, SUBSCRIBE, PUBCOMP, PUBREL, PUBREC, and DISCONNECT. However, some protocols such as UNSUBSCRIBE, UNSUBACK, PINGREQ, PINGRESP, and SUBACK are not initially provided. To use these additional protocols, users can create a new directory within mqtt_fuzz/valid-cases, capture the traffic using tools like Wireshark, extract it into a file, place it in the directory, and add a new session to the session_structures list [15][16]

The implementation of the fuzzer is in Python and relies on Radamsa, which converts random strings, and Twisted, a network engine library for sending MQTT messages. The fuzzer follows a predefined sequence of MQTT control packets for transmission. Additionally, users have the flexibility to include their own raw control packet data in addition to the built-in packets by placing them in the mqtt_fuzz/valid-cases directory.

When using mqtt_fuzz [17], fuzzing can be performed by specifying the ratio and transmission period of mutated control packets through options such as normal control packets and radamsa. However, it is important to note that if all CONNECT packets are mutated through radamsa, fuzzing may not reach the state after the CONNECT control packet. Furthermore, the fuzzer's process is terminated if the server does not respond to new connections.

The control messages sent by mqtt_fuzz are logged using base64 encoding. The fuzzer supports fuzzing in two network environments: (1) running as a localhost on the server where RabbitMQ is installed, which does not require a message authentication account and password; and (2) running on a server within a network composed of multiple hosts where RabbitMQ is installed. In the second method, the RabbitMQ server is recognized using the guest account with a message authentication account and password. The RabbitMQ log displayed in Figure 1 confirms that only messages from the localhost are processed when received by the guest account, and messages from external sources are not received.

B. Fuzzing Protocol

Before getting into the technical aspects, the background of protocol fuzzing is presented [18]. The first fuzzing tool for testing UNIX programs was created by Miller et al [9], and since then, there has been a substantial amount of research on UNIX utilities and services. These investigations initially focused mostly on developing the suggested fuzzing method in order to find more software problems.

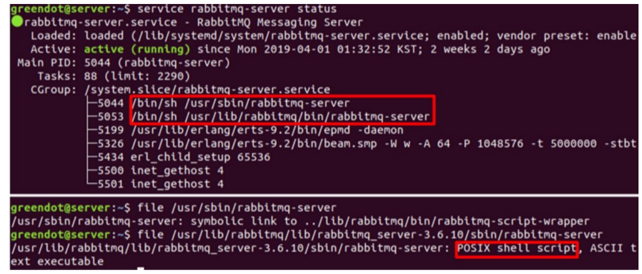


Figure 1 Executable script of the RabbitMQ server

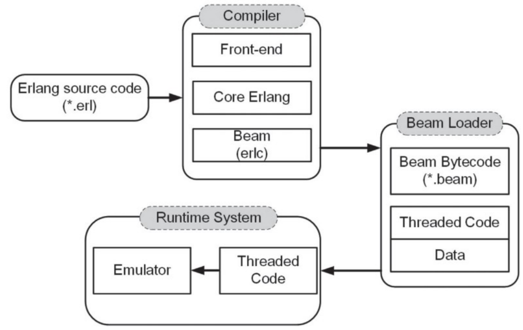


Figure 2 Erlang program running process

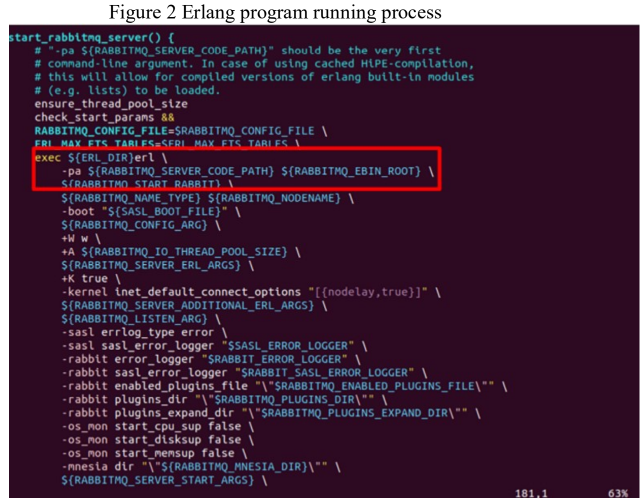


Figure 3 RabbitMQ service run script

In addition, the development of program-based white box fuzzing technology has been developed in order to obtain effective code coverage [19]. With the use of program-specific input grammar, this method fuzzes test cases. As a result of these investigations, fuzzing technology has advanced, and researchers are now investigating how to use it to find defects in network protocols as well as software. Peach and SPIKE fuzzer, two well-known fuzzing tools, were developed to fuzz protocols by converting their specifications into XML files and templates. The drawbacks of these fuzzers are that each new protocol that is tested necessitates the setting of input data files and a time-consuming manual inspection of the protocol specifications [20][21]. Furthermore [7], in order to obtain good code coverage, the development of program-based white box fuzzing technology has been studied. With the use of program-specific input grammar, this method fuzzes test cases. As a result of these investigations, fuzzing technology has advanced, and researchers are now investigating how to use it to find defects in network protocols as well as software.

Peach and SPIKE fuzzer, two well-known fuzzing tools, were developed to fuzz protocols by converting their specifications into XML files and templates [2]. The drawbacks of these fuzzers are that each new protocol that is tested necessitates the setting of input data files and a time-consuming manual inspection of the protocol specifications. Several research have stressed the significance of proactively discovering protocol vulnerabilities. One study, for instance, showed how to employ protocol fuzzing to find possible weaknesses in the MAVLink protocol, which enables two-way communication between drones and ground control stations. Drones are often utilized in a variety of industries, and the communication line between the remote control and the ground control station is open to intrusion. The study used protocol fuzzing while already being familiar with the MAVLink message format. An implementation of a Python-based fuzzer was made possible by using dump fuzzing to examine how the protocol handles faulty input data. The format of the fuzzed input data was "Length + Seq + CompID + MsgID + Payload + Seed." The MAVLink protocol was fuzzed using this fuzzer, and the results showed exceptions that attackers could exploit to disrupt services or cause physical harm. In another study, protocol fuzzing was used to detect faults and vulnerabilities in the implementation of industrial network protocols (INPs). Cyber dangers exist for industrial control systems, which are essential for running infrastructure like power plants. The INP protocol, intended for controlled communication and real-time interference prevention, is vulnerable to interception and abuse. Deep learning-based protocol fuzzing utilizing GANFuzz was carried out on the INP protocol to proactively find such security issues. GANFuzz automatically represents the protocol grammar of actual protocol messages using the GAN and SeqGan algorithms. MSG Preprocessing, Training and MSG Generating, MSG Sending, Monitoring, and Logging are some of the modules that make up this system. As shown in Table 1, these modules work together to complete the fuzzing process, and Figure 4 shows how they are configured.

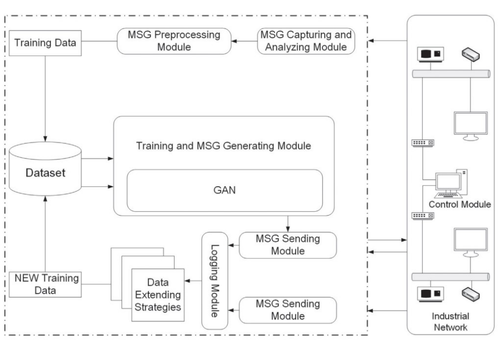


Figure 4 GANFuzz architecture

TABLE I
OPERATIONS OF THE GANFUZZ MODULES

Module	Description
MSG capturing and analyzing module	Network communication collection and analysis
MSG preprocessing module	Prepare data for training
Training and MSG Generating module	Create deep learning training and test cases
MSG sending module	Send/receive messages to industrial networks
Monitoring module	Monitoring industrial networks for abnormalities during fuzzing
Logging Module	Record all events that occurred during fuzzing process

Furthermore, during the investigation, it was discovered that MQTT messages contained sensitive data such as email addresses and location names, specifically associated with a particular company. The records revealed that employees from large corporations were making reservations using their business email addresses, leaving their offices, or taking taxis. These records included precise timing information, which could enable an attacker to track the movements of critical employees. This information poses numerous risks, as attackers gain insights into the targeted company's employees and their activities. With this knowledge, attackers can plan targeted attacks on the smart city control system or exploit vulnerabilities in individual devices within the smart city infrastructure.

As previously mentioned, extensive research has been conducted in various fields to identify vulnerabilities in protocols through protocol fuzzing. Building upon these studies, this paper aims to discover potential vulnerabilities by fuzzing the MQTT protocol used in RabbitMQ, a prominent message broker employed in IoT device-to-device communication. Section 3.3 of this paper will outline the fuzzing method using mqtt_fuzz, providing insights into the operation analysis of mqtt_fuzz and its applicability to the actual MQTT protocol used in RabbitMQ.

C. Testbed Configuration

The testbed configuration for the research on Fuzzing Protocol Effectiveness in Data Communication Security on RabbitMQ consists of several components. Firstly, the researchers set up a network environment that includes multiple hosts. This network environment is crucial for simulating real-world scenarios and testing the effectiveness of the fuzzing technique on RabbitMQ. Secondly, RabbitMQ is installed on the designated server within the network shown at fgure 5. This installation serves as the target for the fuzzing process, allowing the researchers to evaluate the security vulnerabilities and potential risks in the RabbitMQ protocol.

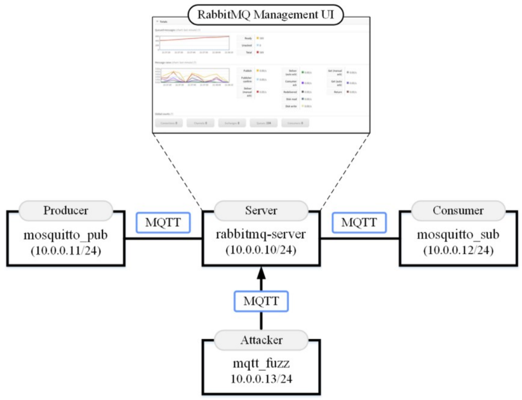


Figure 5 Testbed configuration

To facilitate the fuzzing process, the researchers configure the mqtt_fuzz fuzzer. The fuzzer is implemented in Python and utilizes Radamsa, a random string converter, and Twisted, a network engine library, to generate and send MQTT messages. The mqtt_fuzz tool is tailored to the MQTT protocol used in RabbitMQ, and the predefined control packets are modified and mutated according to the specified options. Additionally, the researchers configure logging mechanisms to capture the control messages sent by mqtt_fuzz. These messages are logged using base64 encoding, enabling the researchers to analyze the generated fuzzed inputs and evaluate the impact on RabbitMQ's security.

Overall, the testbed configuration includes the establishment of a network environment, installation of RabbitMQ, and configuration of the mqtt_fuzz fuzzer with proper logging mechanisms. This configuration enables the researchers to conduct the fuzzing process effectively and assess the protocol's security vulnerabilities in RabbitMQ. We established a dedicated testbed for conducting protocol fuzzing experiments. The fuzzing process was executed on this testbed. To effectively monitor RabbitMQ's behavior during the fuzzing process, the server established a connection to the management plugin address "http://localhost:15672" and monitored the contents of the log file. Both producers and consumers were able to publish and subscribe to messages, ensuring the test environment's functionality. The fuzzing process was initiated by executing the mqtt_fuzz tool using a specific command, as illustrated in Figure 6.

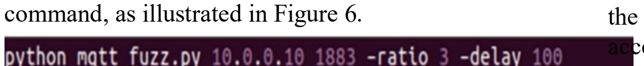


Figure 6 mqtt_fuzz run command

The command instructed the mqtt_fuzz tool to send messages at regular intervals of 100 milliseconds, focusing on fuzzing only three out of the ten pre-defined MQTT packets. The fuzzing process was targeted at port 1883 on the RabbitMQ server, identified by the IP address 10.0.0.10. In order to detect vulnerabilities through mqtt_fuzz, multiple instances of the tool were executed and operated simultaneously. The ongoing fuzzing process, as observed in Figure 7.

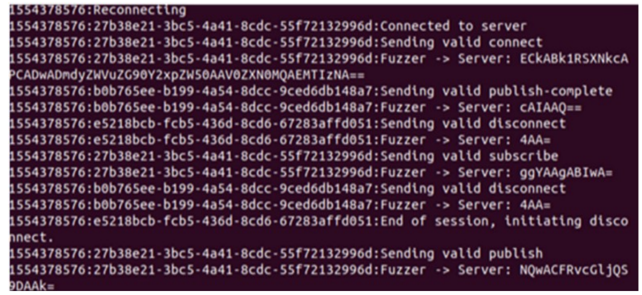


Figure 7 mqtt_fuzz running screen

Results and Discussion

During several rounds of fuzzing using the mqtt_fuzz protocol fuzzing tool, abnormalities were observed in a section of the RabbitMQ server's management UI. While the management plugin could typically be accessed by administrators, allowing them to configure and monitor queues through the "Queues" tab, it was noticed that attempting to access this tab resulted in no response. To confirm this issue, we examined the RabbitMQ log file located at "/var/log/rabbitmq."

The log file analysis revealed an "ERROR REPORT" containing the specific error message related to accessing the "Queues" tab. The error was attributed to the presence of a "bad_utf8_character_code" and exposed a vulnerability that displayed the administrator's account ID, along with the plaintext password and associated account tags. The contents of the "ERROR REPORT" section from the RabbitMQ log file can be seen in Figure 8.

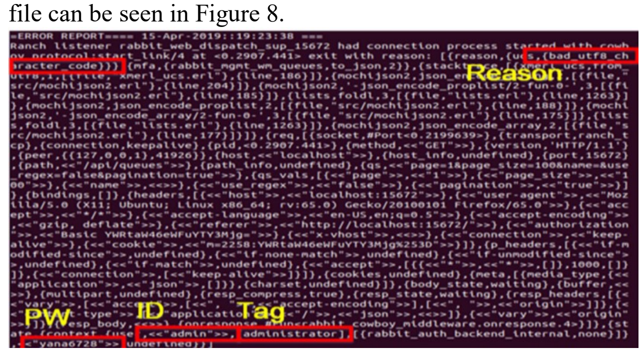


Figure 8 'ERROR REPORT' in the RabbitMQ log file

Furthermore, Figure 9 indicates that the log file can be accessed by accounts other than the file owner or the file owner group. This implies that unauthorized access to the log file could expose the administrator's account details in plain text, enabling malicious interference with message transmission from the management UI or facilitating malicious actions by unauthorized individuals.

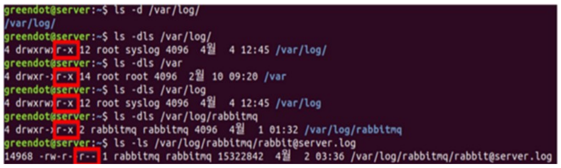
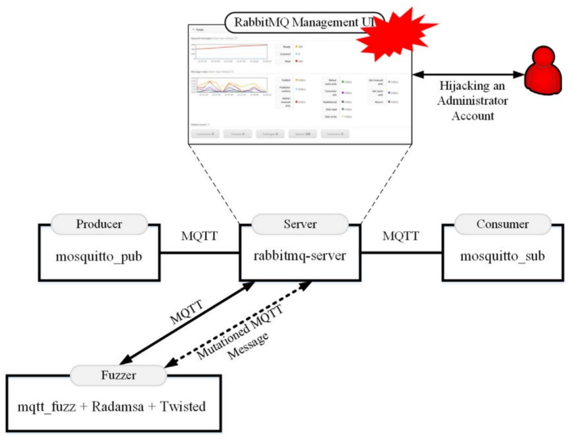


Figure 9 Logfile Location Permission

For instance, in critical infrastructure like a nuclear power plant, if an attacker were to hijack the administrator UI account information through this vulnerability, they could cause significant physical and financial damage to the country by manipulating messages sent to crucial systems such as cooling furnaces. This scenario is depicted in Figure 8, where the attacker hijacks the account information from the administrator UI and utilizes it to disrupt normal message transmission between the message broker and the devices, or even seize control of the messages, thereby impeding the proper functioning of the devices.



It was verified that the cause of the crash was related to the encoding of the client ID field in the MQTT packet. When mqtt_fuzz randomly modified the values in the packet and encoded the client ID field in a format other than UTF-8, the crash occurred. While injecting unknown random strings in the client field of the MQTT packet and encoding them in UTF-8 worked normally, encoding a regular string in a format other than UTF-8 led to the aforementioned crash.

To reproduce the discovered vulnerabilities, it would be time-consuming to rely on random packet transmissions and injections to identify when the same crash occurs. Therefore, an exploit tool was developed to promptly reproduce the crash. This exploit tool, written in Python, takes the RabbitMQ account ID and password as parameters and sets them in the MQTT packet. It also encodes the string "test" into base64_codec and assigns it to the client ID field. By continuously subscribing to a specific topic on the message broker through the configured MQTT packet, the exploit tool is able to reproduce the crash. When the administrator clicks the "Queues" tab in the RabbitMQ management UI while the exploit tool is running, no response is received. At this point, pressing "Enter" in the exploit tool triggers an SSH connection to another account on the server where RabbitMQ is installed. Subsequently, the exploit tool accesses the RabbitMQ log file and retrieves the exposed account details, displaying them on the screen.

Conclusions and Recommendations

In conclusion, the study on Fuzzing Protocol Effectiveness in Data Communication Security on RabbitMQ provided valuable insights into the vulnerabilities and risks associated with the MQTT protocol used in RabbitMQ. Through protocol fuzzing techniques, several vulnerabilities were identified, including crashes and exposure of sensitive information such as account IDs and passwords. These vulnerabilities highlight the potential for unauthorized access, interference with message transmission, and the potential for malicious actions within the RabbitMQ environment.

The research demonstrated the effectiveness of applying fuzzing techniques to identify and proactively mitigate security weaknesses in the MQTT protocol. By utilizing the mqtt_fuzz fuzzer, various scenarios were tested, and the impact of malformed packets on the RabbitMQ server was assessed. Additionally, the development of an exploit tool allowed for the quick reproduction of crashes and the exploitation of identified vulnerabilities, emphasizing the urgent need for adequate security measures.

The findings underscore the importance of continuous monitoring, updating, and patching of the RabbitMQ system to protect against potential attacks and maintain the integrity and confidentiality of data communication. It is crucial to address the identified vulnerabilities promptly and implement appropriate security controls to safeguard against unauthorized access and potential disruptions to critical services.

Overall, this study emphasizes the significance of fuzzing as an effective approach to evaluate and enhance the security of data communication protocols, particularly in the context of RabbitMQ. The insights gained from this research can contribute to the development of more robust and secure messaging systems, mitigating potential risks and ensuring the confidentiality, integrity, and availability of sensitive information exchanged within RabbitMQ and similar environments.

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