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Honeypot Implementation in a Cloud Environment

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Erklärung:

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Heidelberg, den (Datum) .....

Acknowledgements

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Acronyms

ACL Access Control List

ADB Android Debug Bridge

ADC Application Delivery Controller

ASA Adaptive Security Appliance

AWS Amazon Web Services

BelWÜ Baden-Württembergs extended LAN

BPP Binary Packet Protocol

CERT Computer Emergency Response Team

CHARGEN Character Generator Protocol

CVE Common Vulnerabilities and Exposures

DaaS Data-as-a-Service

DDoS Distributed Denial of Service

DICOM Digital Imaging and Communications in Medicine

DMZ demilitarized zone

DNS Domain Name System

DTK Deception Toolkit

EU European Union

FHIR Fast Healthcare Interoperability Resources

GCP Google Cloud Platform

HaaS Hardware-as-a-Service

HTTP Hypertext Transfer Protocol

IaaS Infrastructure-as-a-Service

ICS Industrial control systems

IDS intrusion detection system

IPD intrusion prevention system

IPP Internet Printing Protocol

MAC Message Authentication Code

NIST National Institute of Standards and Technology

NSM network security monitoring

NTP Network Time Protocol

OS operating system

PaaS Platform-as-a-Service

RDP Remote Desktop Protocol

SaaS Software-as-a-Service

SCADA Supervisory Control and Data Acquisition

SNMP Simple Network Management Protocol

SOHO Small Office Home Office

SSDP Simple Service Discovery Protocol

VM virtual machine

VMM virtual machine monitors

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Introduction

Chapter 2

Background

Using honeypots in a cloud environment merge two varying principals together. This chapter introduces the fundamental knowledge that is needed to comprehend the upcoming experiments. If the reader has a profound understanding of cloud computing, honeypots, and virtualization he can skip this chapter.

2.1 Virtualization

Virtualization, often referred to virtual machine (VM), is defined by Kreuter [45] as "an abstraction layer or environment between hardware component and the end-user". A VM runs on top of an operating system (OS) core components. Through an abstraction layer, the virtual machine is connected with the real machine by hypervisors or virtual machine monitors (VMM). Hypervisors can use real machine hardware components, but also support virtual machine operating systems and configurations. Both are similar to emulators, that are defined by HA [33] as "process whereby one computer is set up to permit the execution of programs written for another computer". This allows to manage multiple VM with real machine resources. There are three different types of virtualization, (i) software virtual machines, (ii) hardware virtual machines, and (iii) virtual OS/containers. Software virtual machine's manage interactions between the host operating system and guest operating system. Hardware virtual machine's offers direct and fast access to the underlying resources. It uses hypervisors, modified code, or APIs. Lastly, virtual OS/container partitions the host operating system into containers or zones. [22]

2.2 Cloud Computing

Cloud Computing has become a very popular keyword these days. It has been used by various large companies such as Google and Amazon. However, the term "cloud computing" dates back to the late 1996, when a small group of technology executives

of Compaq Computer framed new business ideas around the Internet.[57] Starting from 2007 cloud computing evolved into a serious competitor and outnumbered the keywords "virtualization", and "grid computing" as reported by Google trends [75]. Shortly, various cloud provider become publicly available, each with their own strengths and weaknesses. For example IBM's Cloud[1], Amazon Web Services[2], and Google Cloud[3]. Why are clouds so attractive in practice?

- It offers major advantages in terms of cost and reliability. When demand is needed, consumers do not have to invest in hardware when launching new services. Pay-as-you-go allows flexibility.
- Consumer can easily scale with demand. When more computational resources are required due to more requests, scaling up instances in conjunction with a suited price model are straightforward.
- Geographically distributed capabilities supply the need for world-wide scattered services.

2.2.1 Definition of Cloud Computing

With reference to the definition by Brian Hayes, cloud computing is "a shift in the geography of computation" [34]. Thus, computational workload is moved away from local instances towards services and datacenters that provide the user's needs[3].

The National Institute of Standards and Technology (NIST) defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [48]. NIST not only reflects the geographical shift of resources such as datacenters, but also mentions on-demand usage that contributes to a flexible resource management. Moreover, NIST composes the term in five essential characteristics, three service models (see subsection 2.2.2), and four deployment models (see subsection 2.2.3) [48]

On-demand-self-service refers to the unilaterally provision computing capabilities. Consumers can acquire server time and network storage on demand without a human interaction.

Broad network access characterizes the access of capabilities of the network through standard protocols such as Hypertext Transfer Protocol (HTTP). Heterogeneous thin and thick client platforms should be supported.

[1] `https://www.ibm.com/cloud`
[2] `https://aws.amazon.com/`
[3] `https://cloud.google.com/`

Resource pooling allows the provider's computing resources to be pooled across several consumers. A multi-tanent model with different physical and virtual resources are assigned on demand. Other aspects such as location are independent and cannot be controlled on a low-level by consumers. Moreover, high-level access to specify continent, state, or datacenter can be available.

Rapid elasticity offers consumers to extend and release capabilities easily. Further automatization to quickly increase resources when demand skyrockets significantly can be supported regardless limit and quantity at any time.

Measured service handles resources in an automated and optimized manner. It uses additional metering capabilities to trace storage, processing, bandwidth, and active user accounts. This helps to monitor, and control resource usage. Thus, contributing to transparency between provider and consumer.

2.2.2 Service models

Service models are categorized by NIST into three basic models based on usage and abstraction level. Figure 2.1 shows the connection between each model whereas cloud resource are defined in subsection 2.2.3. Due to the vast range of functionalities, Infrastructure-as-a-Service (IaaS) builds the foundation of service models. Each model on top represents a user-friendly abstraction with derated capabilities.

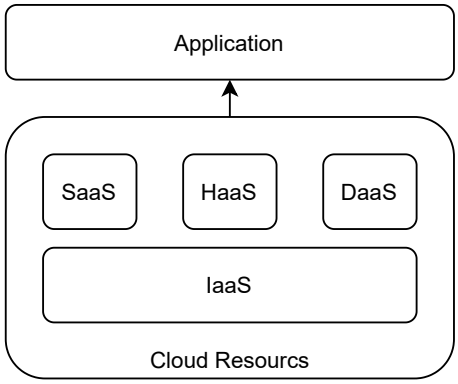


Figure 2.1: Abstract visualization of service models. The lowest level within the container "cloud resources" represents the depth of functionalities. Therefore, Infrastructure-as-a-Service (IaaS) offers the most functionalities whereas the others have a user-friendly abstraction.

Software-as-a-Service (SaaS) is a high-level abstraction to consumers. Controlling the underlying infrastructure is not supported. Providers often use a multi-tenancy system architecture to organize each consumer's application in a separate environment. It helps to employ scaling with respect to speed, security availability, disaster recovery, and maintenance. Main objective of SaaS is to host consumer's software or

application that can be accessed over the Internet using either a thin or rich client. [25] "Limited user-specific application configuration settings" can be made [48].

Platform-as-a-Service (PaaS) pivots on the full "Software Lifecycle" of an application whereas SaaS distinct on hosting complete applications. PaaS offers ongoing development and includes programming environment, tools, configuration management, and other services. In addition, the underlying infrastructure is not managed by the consumer. [48]

Infrastructure-as-a-Service (IaaS) offers a low-level abstraction to consumers with the ability to run arbitrary software regardless of operating system or application. In contrast to SaaS, IT infrastructures capabilities (such as storage, networks) can be used. It strongly depends on virtualization due to integration, or decomposition of physical resources. [48]

Data-as-a-Service (DaaS) serves as a virtualized data storage service on demand. Motivations behind such services could be upfront costs of on-premise enterprise database systems. [25] Mostly they require "dedicated server, software license, post-delivery services, and in-house IT maintenance" [25] Whereas DaaS costs solely what consumer's need. When dealing with a tremendous amount of data, file systems and RDBMS often lack in performance. DaaS outruns such weak links by employing a table-style abstraction that can be scaled.[25]

Hardware-as-a-Service (HaaS) offers IT hardware, or datacenters to buy as a pay-as-you-go subscription service. The term dates back to 2006 during a time when hardware virtualization became more powerful. It is flexible, scalable and manageable.[75]

2.2.3 Deployment models

Deployment models are categorized by NIST into four basic models. Each differs in data privacy, location, and manageability [48].

Private clouds offer the highest level of control in regard of data privacy, and utilization. Mostly, such clouds are deployed within in a single organization, either managed by in-house teams or third party suppliers. In addition, it can be on or off premise. Within private clouds consumers have full control of their data. Especially for European data privacy laws, it is not negligible when data is stored abroad and thus under law of foreign countries. However, its popularity has not been diminished due to the immense cost of switching to public clouds. [25, 48]

Community clouds can be seen as a conglomerate of multiple organizations that merge their infrastructure with respect to a commonly defined policy, terms, and condition beforehand. [48]

Public clouds represent the most used deployment models. In contrary, to private one, public clouds are fully owned by the service provider such as business, academics, or government organization. Consumers do not know where their data is distributed. In addition, contracts underlie custom policies. [48]

Hybrid cloud is a mixture of two or more cloud infrastructures, such as private and public cloud. However, each entity keeps its core element. Hybrid clouds defines "standardized or proprietary technology to enables data and application portability"[48].

2.3 Honeypots

The term "honeypot" exists since more than a decade. 1997 was the first time that a free honeypot solution became public. Deception Toolkit (DTK), developed by Fred Cohen, released the first honeypot solution. However, the earliest drafts of honeypots are from 1990/91, and built the foundation for Fred Cohen's DTK. Clifford Stoll's book "The Cuckoo's Egg"[67], and Bill Cheswick's whitepaper "An Evening With Berferd"[8] describe concepts that are considered nowadays as honeypots.[66] A honeypot itself is a security instrument that collects information on buzzing attacks. It disguises itself as a system, or application with weak links, so that it gets exploited and gathers knowledge about the adversary. In 2002 a Solaris honeypot helped to detect an unknown `dtspcd` exploit. Interestingly, a year before in 2001 the Coordination Center of Computer Emergency Response Team (CERT), "an expert group that handles computer security incidents"[31], shared their concerns regarding the dtspcd. Communities were aware that the service could be exploited to get access and remotely compromise any Unix system. However, during this time such an exploit was not known, and experts did not expect any in the near future. Gladly, early instances based on honeypot technologies could detect new exploits and avoid further incidents. Such events lay emphasis on the importance of honeypots.

2.3.1 Definition of a Honeypot

A Dozen of definitions for honeypots circulate through the web that causes confusion, and misunderstandings. In general, the objective of a honeypot is to gather information about attacks, or attack patterns [51]. Thus, contributing as an additional source of security measure. See subsection 2.3.3 for a detailed view regarding honeypots in the security concept. As Spitzner [66] has listed, most misleading definitions are: honeypot is a tool for deception, it is a weapon to lure adversaries, or a part of an intrusion detection system. In order to get a basic understanding, we want to exhibit some key definitions. Spitzner [66] defines honeypots as a "security resource whose value lies in being probed, attacked, or compromised". Independent

of its source (e.g. server, application, or router), we expect that our instance is getting probed, attacked, and eventually exploited. If a honeypot does not match this behaviour, it will not provide any value. It is important to mention that honeypots do not have any production value, thus, any communication that is acquired is suspicious by nature [66]. In addition, Spitzner Spitzner [66] points out that honeypots are not bounded to solve a single problem, hence, they function as a generic perimeter, and fit into different situation. Such functions are attack detection, capturing automated attacks, or alert/warning generator. Figure 2.2 show an example how honeypots could be used in an IT infrastructure.

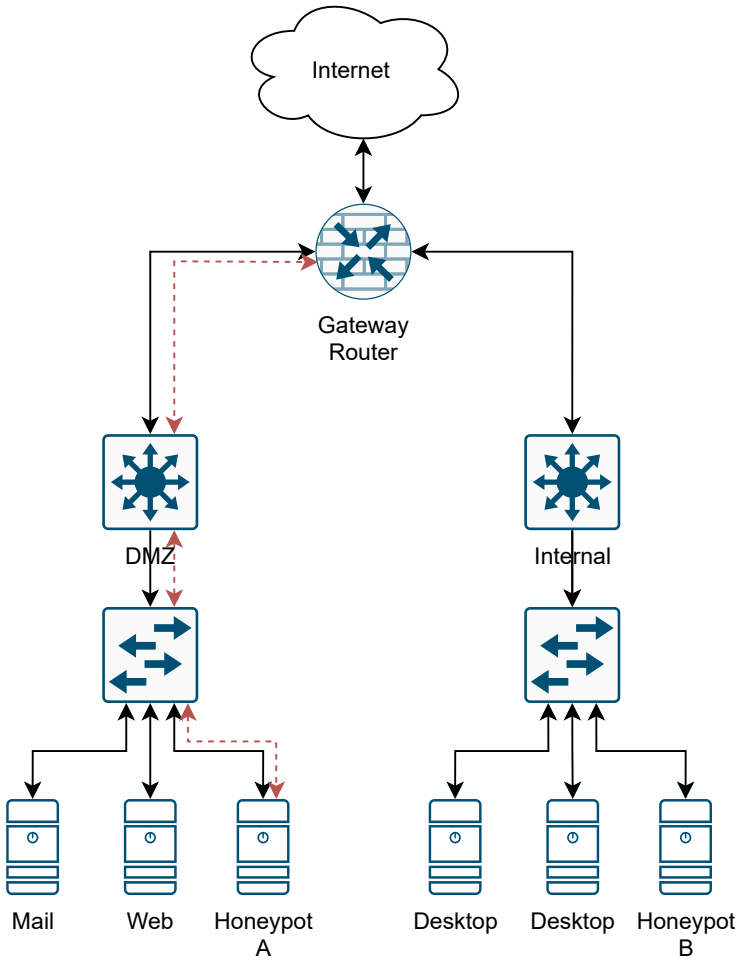


Figure 2.2: Example of honeypots in a simplified network (derived from [66]). Each of the demilitarized zone (DMZ), and internal network are separated by a router and a Layer-3 switch. As derived from above, in each network a honeypot is available (honeypot A, B). The read path symbolizes the path of an attacker coming from the gateway router.

In general, we differentiate two types of honeypots (i) Production honeypots (ii) Research honeypots. This categorization has their origin from Mark Rosch developer of Snort during his work at GTE Internetworking.

Production honeypots are the common type of honeypots that people would think of. The objective is to protect production environments, and to mitigate the risk of attacks. Normally, production honeypots are easy to deploy within an organization. Mostly, low-interaction honeypots are chosen due to a significant reduce in risk. Thus, adversaries might not be able to exploit honeypots to attack other systems. The downside of a low-interaction honeypot is a lack of information, for example standard information like the origin of attacks, or what exploits are used can be collected, whereas insides about communication of attackers, or deployment of such attacks are unlikely to obtain. In contrast, research honeypots do fulfill this objective.[66]

Research honeypots are used to learn more in detail about attacks. The objective is to collect information about the clandestine organizations, new tools for attacks, or the origin of attacks. Research honeypots are unlikely suitable for production environments due to a higher increase of risk. Facing an increase in deployment complexity, and maintenance does not attract a production usage.[66]

It is worth to mention that there is no exact line between research or production honeypots. Possible cases are honeypots that could function as either a production or a research honeypot. Due to their dynamic range in which they are applicable it makes it hard to distinguish.

Provos [56] adds a differentiation for the virtual honeypot framework and splits it into the following types:

- Physical honeypots are "real machines on the network with its own IP address" [56]
- Virtual honeypots are "simulated by another machine that responds to network traffic sent to the virtual honeypot" [56]

2.3.2 Level of Interaction

When building and deploying a honeypot, the depth of information has to be defined beforehand. Should it gather unauthorized activities, such as an NMAP scan? Do you want to learn about buzzing tools and tactics? Each depth brings a different level of interaction because some information depends on more actions of adversaries. Therefore, honeypots differ in level of interaction.

Low-interaction honeypots provide the lowest level of interaction between an attacker and a system. Only a small set of services like SSH, Telnet, or FTP are supported which contributes to the deployment time. In terms of risk, a low-interaction

honeypot does not give access to the underlying OS which makes it safe to use in a production environment. For example using an SSH honeypot, such services are emulated, thus, attackers can attempt to log in by brute force or by guessing, and execute commands. However, the adversary will never gain more access because it is not a real OS. However, safety comes with the downside of less information. Collected is limited for statistical purpose such as (i) Time and data of attack (ii) Source IP address and source port of the attack (iii) Destination IP address and destination port of the attack. Transactional information can not be collected. [66]

A medium-interaction honeypot offers more sophisticated services with higher level of interaction. It is capable to respond to certain activities. For example a Microsoft IIS Web server honeypot could be able to respond in a way that a worm is expecting it. The worm would get emulated answers, and could be able to interact with it more in detail. Thus, gathering more severe information about the attack, including privilege assessment, toolkit capturing, and command execution. In comparison, medium-interaction honeypots allocate more time to install and configure. Also, more security checks have to be performed due to a higher interaction level than low-interaction honeypots. [66]

High-interaction honeypots are the highest level interaction. Mostly, they represent a real OS to provide a full set of interactions to attackers. They are so powerful because other production servers do not differ much to high-interaction honeypots. They represent real systems in a controlled environment. Obviously, the amount of information is tremendous. It helps to learn about (i) new tools (ii) finding new bugs in the OS (iii) the black hat community. However, the risk of such a honeypot is extremely high. It needs severe deployment and maintenance processes. Therefore, it is time-consuming.

2.3.3 Security concepts

Security concepts are classified by Schneier [64] in prevention, detection, and reaction. Prevention includes any process that (i) discourages intruders and (ii) hardens systems to avoid any kind of breaches. Detection scrutinizes the identification of attacks that threatens the systems' (i) confidentiality (ii) integrity and (iii) availability. Reaction treats the active part of the security concept. When attacks are detected, in conducts reactive measures to remove the threat. Each part is designed to be sophisticated so that all of them contribute to a secure environment. [51]

Honeypots contribute to the security concept like firewalls, or intrusion detection system (IDS). Regarding prevention, honeypots add only a small value because security breaches cannot be identified. Moreover, attackers would avoid wasting time on honeypots and go straight for production systems instead.

However, detection is one of the strengths of honeypots. Attacks often vanish in the sheer quantity of production activities. If any connection is obtained to a honeypot

it is suspicious by nature. In conjunction with an alerting tool, attacks can be detected.

Honeypots strongly supply reaction tools due to their clear data. In production environments, finding attacks for further data analysis are not easy to grasp. Often data submerge with other activities which complicates the process of reaction. [51] Nawrocki et al. [51] distinct honeypots from other objectives such as firewall, or log-monitoring.

Table 2.1: Distinction between security concepts based on areas of operations (derived from [51]).

Objective	**Prevention**	**Detection**	**Reaction**
Honeypot	+	++	+++
Firewall	+++	++	+
Intrusion Detection Sys.	+	+++	+
Intrusion Prevention Sys.	++	+++	++
Anti-Virus	++	++	++
Log-Monitoring	+	++	+
Cybersecurity Standard	+++	+	+

2.3.4 Value of Honeypots

To assess the value of honeypots we want to take a closer look to their advantages and disadvantages.[50, 40, 66]

Advantages

- Data Value: Collected data is often immaculate and does not contain noise from other activities. Thus, reducing the total size of data, and speeding up the analyzation.
- Resources: Firewalls, and IDS are often overwhelmed by the gigabits of traffic, thus, dropping network packets for analyzation. This results in a far less effective detection for malicious network activities. However, honeypots are independent of resources because they only capture their activities at itself. Due to resource limitation, expensive hardware is not needed.
- Simplicity: A honeypot do not require any complex algorithms, or databases. It should be able to quickly deploy it somewhere. Research honeypots might come with a certain increase of complexity. However, if a honeypot is complex, it will lead to misconfigurations, breakdowns, and failures.

- Return on Investment: Capturing attacks immediately informs users that attack occur on the infrastructure. This helps to demonstrate their value, and contributes to new investment in other security measurements.

In addition, Nawrocki et al. [51] listed four more advantages of honeypots:

- Independent of Workload: Honeypots only process traffic that is direct to them.
- Zero-Day-Exploit Detection: It helps to detect unknown strategies and zero-day-exploits.
- Flexibility: Well-adjusted honeypots for a variety of specific tasks are available.
- Reduced False Positives and Negatives: Any traffic or connection to a honeypot is suspicious. Client-honeypots verify such attacks based on system state changes. This results in either false positive, or false positive.

Disadvantages

- Narrow Field of View: Only direct attacks on honeypots can be investigated whereas attacks on production system are not detected by it.
- Fingerprinting: A honeypot often has a certain fingerprint that can be identified by attackers. Especially commercial ones can be detected by their responses or behaviors.
- Risk to the Environment: Using honeypots in an environment always increase the risk. However, it depends on the level of interaction.

2.3.5 Honeynets

Instead of having single honeypots that can be attacked, a honeynet offers a complete network of standard production systems such as you would find in an organization. Those systems are high-interaction honeypots, thus, allowing to fully interact with the OS, and applications. Key idea is that an adversary can probe, attack, and exploit these systems so that we can derive interaction within this network. It should be mentioned that a honeynet have to be protected by firewall. Figure 2.3 represents such a honeynet within an organization.

In comparison to regular honeypot, the greatest value of honeynets is the usage of true production systems. Black hats often do not know that they attack a honeynet, thus, adding value to prevention. However, the downsides are high complexity and maintenance that is needed to keep a honeynet running. [66]

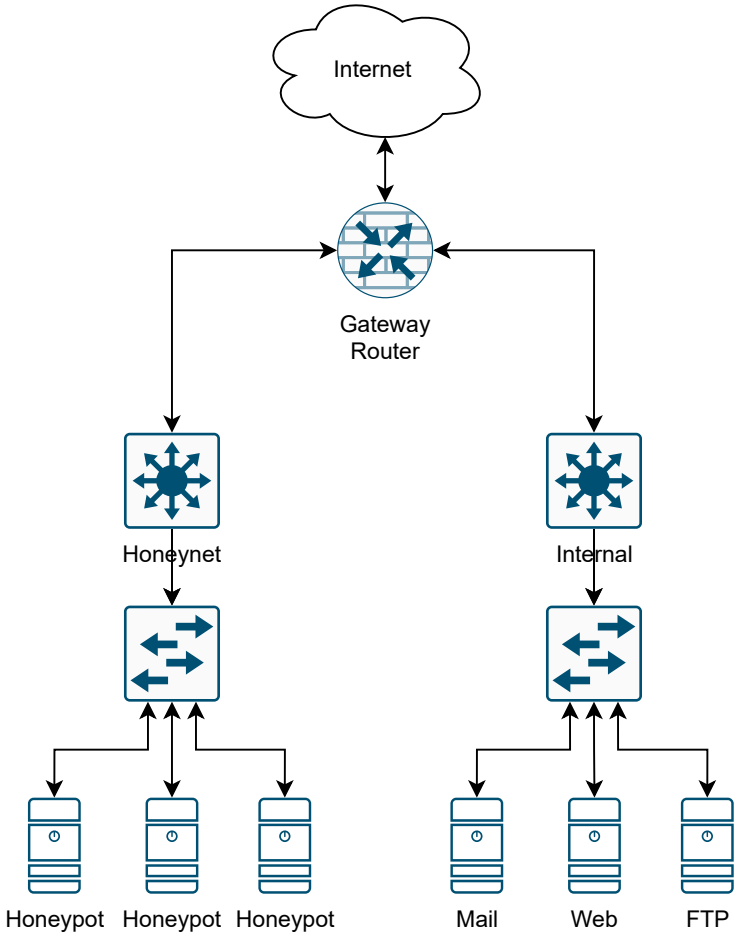


Figure 2.3: Example of honeynets in a simplified network (derived from [66]). On the left, this network presents the honeynet consisting of several other honeypots. On the right the network presents an ordinary subnet consisting of mail, web, and FTP server.

2.3.6 Legal Issues

Considering questions related to legal issues of honeypots can easily exceed this thesis. In this regard, we restrict the study to the country we reside in. Thus, we are only concerned about the European Union (EU) regulations, EU directives, and international agreements. Honeypots collect (i) content data that is used for communication, and (ii) transactional data that is used to establish the connection. Sokol et al. [65] studied the legal conditions for data collection and data retention. They come to the conclusion that administrators of honeypots have a legal ground of legitimate interest to store and process personal data, such as IP addresses. Moreover, for production honeypots the legitimate interest is to secure services. Regarding the length of data retention, the principle of data minimization has to be consid-

ered which means there is no clear answer for it. Any published data of research honeypots needs to be anonymized.

2.3.7 Related Work

The Snort [7] inline extension *Bait'n'Switch* [1] redirects attackers from production systems to honeypots. Usually Snort drops malicious packets when they are detected, and creates a specific rule to block malicious activity from the source. In contrast, *Bait'n'Switch* does not create a rule to block more request, instead it redirects them to honeypots. The attacker does not realize that all packets are rerouted, and that the original target has changed. The IDS is bounded to its signature database and can only redirect known attacks.[24]

Whereas *Bait'n'Switch* had to drop the first attack which leads to a suspicious behavior for attackers, the *Intrusion Trap System* [69] is capable of forwarding the first request. Therefore, the first recognized attack by the IDS can be forwarded and answered by honeypots. [24]

The *honeyd* [56] extension *Honeycomb* [44] enables automatically generates *Snort* and *Bro* [54] signatures for all incoming traffic. In addition, new signatures are created for similar patterns if they do not exist already, and updating of existing ones to improve their quality. This is based on the incoming traffic, and the corresponding attack session. Even mutations of attacks are considered. It generates a more generic description for signatures in order to match the original attack, and the mutation. It helps to keep the size of signatures small. However, the downside of this extension is the missing verification of attacks. Wrongly redirected traffic will not be proofed if an attack was successful even though a signature has been created. [24]

Chapter 3

Analyze Honeypot Attacks in the Cloud

Attacks from the Internet are often originated from bots. A bot, short for "robot", is an automated process that interacts with different network services. Besides good intentions, bots can be used for malicious purposes. Mostly, bots try to self-propagate malware across the Internet and try to capture hosts that merge into a botnet. A botnet has a central server or servers that act as a command and control center for all infected hosts [29]. Recently, Universities in Germany received more cyberattacks than ever, respectively increasing their costs for damage repairs. Honeypots are a good solution to catch attackers and learn from their exploits. However, there is no conclusion if honeypots in times of bots give a proper countermeasure to avoid such damage. Following the rise of cyberattacks, we introduce a method to collect and analyze cyberattacks in a cloud environment. We further propose an answer if honeypots are helpful to prevent such scenarios from happening.

3.1 Introduction

As previously mention in section 2.2, using cloud resources are becoming the go-to option for new services and applications. Kelly et al. [41] thoroughly investigated honeypots on Azure, Amazon Web Services (AWS), and Google Cloud Platform (GCP). Followingly, we present their results that we want to compare on with the ones heiCLOUD achieves. The results are collected by T-Pot version 20.06.0 over a duration of 3 weeks. In addition, Kelly et al. [41] considered different server geographical locations. They have collected data from East US, West Europe, and Southeast Asia. Table 3.1 shows the results presented by Kelly et al. [41]. Dionaea (a honeypot to capture malicious payload), Cowrie (SSH and Telnet honeypot), and Conpot (industrial honeypot for ICS, and SCADA) are the most attacked honeypots in comparison to the others. Regarding AWS, Dionaea account 91% of the total attacks, Glutton and Cowrie are minor with 5%, and 2%. Interestingly, Cowrie

Table 3.1: Overview of attacks on cloud providers. For a better overview, only the three most attacked honeypots are listed. The others combine several honeypots.

Provider	Honeypot				In Total
	Dionaea	**Cowrie**	**Glutton**	**others**	
Amazon Web Services	228 075	4 503	11 878	3 688	248 144
Google Cloud Platform	162 570	297 818	84 375	36 403	581 116
Microsoft Azure	308 102	9 012	17 256	6 365	340 735

reported several attacks related to the COVID-19 pandemic to enable social engineering methods. In contrast to AWS, Cowrie logged the majority of attacks with 51% on GCP. Beside several automated attacks trying to log in with default credentials, adversaries tried to gather information about CPU architecture, scheduled tasks, and privilege escalation. Microsoft Azure reflects nearly the same results as the other two cloud providers beforehand.

The overall results show an average ratio of 55.000 attacks per day, summing up to roughly 1.3 million in total. Similar results for different regions could have been reproduced. Their results clearly show the disparity of the regions Europe, US, and Asia. An important question that Kelly et al. [41] answered is if attackers target services on cloud providers based on the cloud providers' market share. The study could not confirm this assumption based on the fact that Google Cloud with the smallest market share received most of the attacks. In total, most of the attacks are originated from Vietnam, Russia, United States, and China. Due to technologies such as VPN, or Tor, the geolocation only indicates the last node, so location data might be distorted. Across all providers roughly 80% of the source IP addresses had a bad reputation and could have been filtered by the organization. The operating devices used for attacking the services are mostly Windows 7 or 8, and different Linux kernels and distributions. Windows devices target vulnerabilities in remote desktop sharing software. Such vulnerabilities are (i) CVE-2006-2369[15] (RealVNC) in the US region, (ii) CVE-2001-0540[12] (RDP) in EU and Asia regions, (iii) CVE-2012-0152[16] (RDP) in the Asia region, and (iv) CVE-2005-4050[14] (VoIP) in EU region. In addition, attackers were also capable of disguising any fingerprinting activity of p0f.

We want to compare the findings Kelly et al. [41] claimed in the paper "A Comparative Analysis of Honeypots on Different Cloud Platforms" with ours using the University Heidelberg's cloud solution. First, a short introduction of heiCLOUD is presented, followed by a closer lookup of T-Pot that is used to acquire data. Lastly, we present our results and do a thorough comparison closing up with a discussion based on a technical report of the Cambridge University.

3.2 Methodology

Our foremost goal is to track as many attacks as possible. We want to verify if most of the attacks on the Internet are originated from bots. To gather various attacks from the Internet Figure 3.1 sketches our concept we plan to apply. Honeypots should be deployed on a single instance, and their data, or log files are stored in a database. By the help of data visualization tools, we analyze the attacks. For security reasons, honeypots should run in a virtualized environment to avoid any harm to our host system. We use Debian as a base Linux distribution. Our instance runs on heiCLOUD, a cloud service provided by Heidelberg University. It is capable of 16 GB of RAM, 8 VCPU's, and a volatile memory of 30 GB. In addition, we mount a 125 GB permanent memory to securely store our data. In its very early stages, we compared different approaches to achieve this goal. As an example, we compared native implementation approaches, using additional frameworks, and ready-to-use solutions. However, the T-Pot, developed by Telekom, offers a profoundly ready-to-use solution with major advantages. It combines several honeypots in conjunction with various analytic tools to trace the newest attacks. Furthermore, it helps to compare our findings with the ones Kelly et al. [41] claim.

Running our instance and exposing it to the Internet needs some adjustments beforehand. Therefore, a virtual network with subnet `192.168.145.0/24` has been created wherein our instance with IP address `192.168.145.4` is assigned to. The instance is accessible from the outside with floating IP address `129.206.5.74`. Access rules are similar to a stateful firewall, and thus, do not block any attacks. Ports $1-64000$ are exposed and can be attacked by anyone. Ports higher than 64000 are only accessible through the University network `129.206.0.0/16` or eduroam `147.142.0.0/16` and should provide a basic authentication with username and password.

3.2.1 heiCLOUD

University Computing Center Heidelberg [71] offers a "IaaS specially tailored for higher education and research institutions" called heiCLOUD. It supplies multiple institutes at Heidelberg University with storage, virtual machines, or network components. In addition, heiCLOUD is a DFN[1] member, and offers others to use their services. As stated on their information website[70], it is (i) capable of freely manageable IT resources, (ii) beholds a stable and fast connection, (iii) ensures high availability and scalability, (iv) has freely selectable VM operating systems, and (v) has a transparent payment model [70]. Based on the open source application

[1] German National Research and Education Network, the communications network for Science and research in Germany

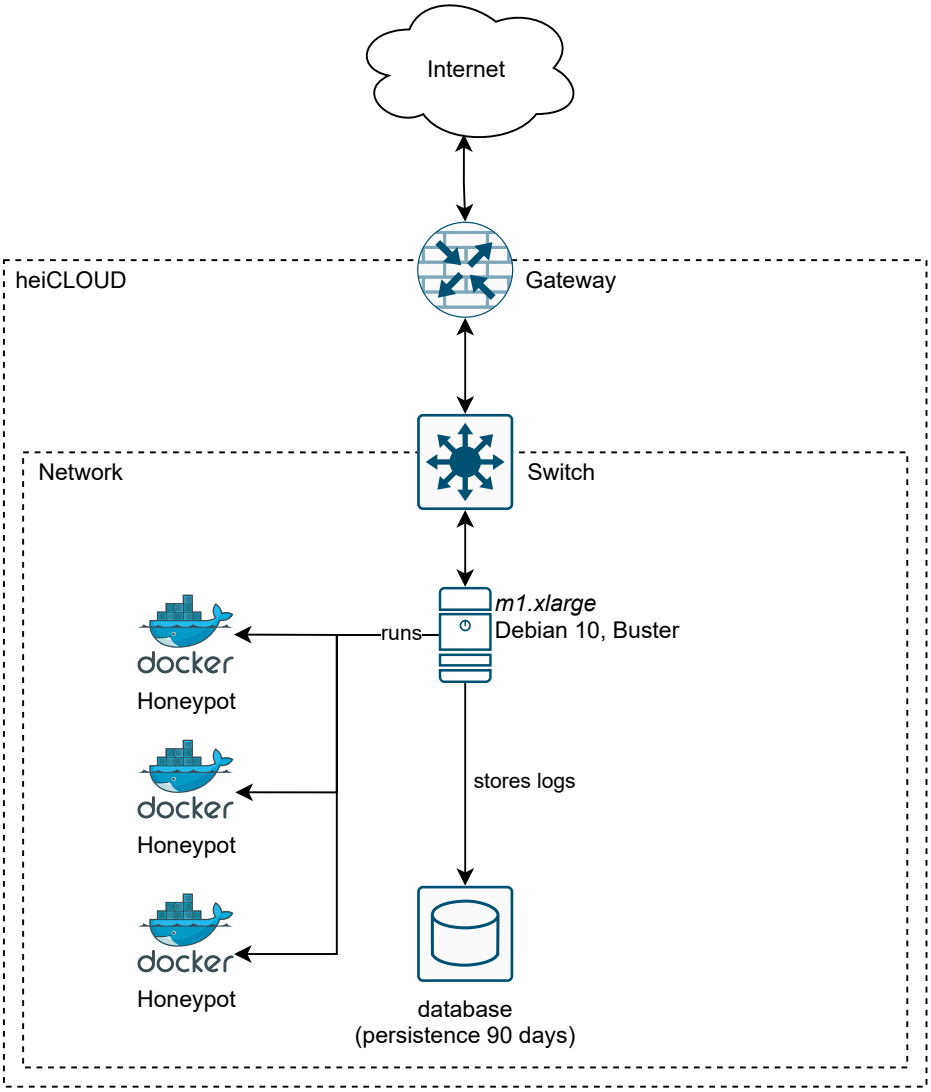


Figure 3.1: Concept to collect honeypot attacks

OpenStack, users can easily create own network areas, and manage their space individually. Unlike well-known cloud providers, heiCLOUD servers are located within Germany, thus, abide by the European data privacy law. HeiCLOUD have never considered honeypots for additional cybersecurity measurements.

3.2.2 T-Pot

To be able to compare our results with Kelly et al. [41], we use the same approach to capture recent cyberattacks. The T-Pot solution, a mixture of Telekom and Honeypot, stands out with their sheer quantity of various honeypots. It requires 8 GB RAM and a minimum of 128 GB hard drive storage. Based on a Debian 10 Buster

distribution, it relies on Docker to run their services [27]. T-Pot has to be deployed in a reachable network where intruders are expected. Either TCP and UDP traffic are forwarded without filtering to the network interface, or it runs behind a firewall with forwarding rules. Specified ports for attackers are 1-64000, higher ports are reserved for trusted IPs, thus, a reverse proxy asks for basic authentication. All daemons and tools run on the same network interface whereas some of them are encapsulated in their own Docker network. Docker is a lightweight virtualization technology that uses containers to run on the host system [10]. Unlike virtual machines, Docker reduces overhead with the downside of a greater attack surface. To mitigate attacks, Docker wraps containers in an isolated environment. This is achieved by restricting the kernel namespace and control groups (`cgroups`). Figure 3.2 visualizes the technical concept of T-Pot. Each service has dedicated ports or port ranges that are exposed. Attackers can communicate either with TCP or UDP. All honeypots and tools create log files that are used to get any knowledge about attackers. In order to view and trace current attacks, T-Pot uses the ELK stack. ELK is the acronym of Elasticsearch, Logstash and Kibana [28]. Elasticsearch is a search engine based on Lucene. It is multitenant-capable and offers full-text search via HTTP. Logstash is used to feed Elasticsearch. In general, it offers an open server-side data processing pipeline that helps to send data from multiple sources to an Elasticsearch node. Kibana is the main data visualization tool. It offers users to create plots and dashboards, crawl Elasticsearch, and trace the system health. All logs of the honeypots and tools are forwarded to the search engine Elasticsearch by Logstash. The ELK stack is not directly exposed to the Internet, thus, an authentication is not needed. Users can monitor all log files with Kibana by pre-defined dashboards, or custom search queries. In addition, T-Pot features different services types, namely (i) standard, (ii) sensor, (iii) industrial, (iv) collector, (v) next generation, and (vi) medical. Each service type has a different set of honeypots and tools tailored to their core idea. T-Pot feeds their data to an external Telekom service, however, this data submission can be turned off. For this chapter we restrict ourselves to the latest version 20.06.0. Newer versions might be available by the end of this study and could differ from ours.

Honeypots

T-Pot consists of 20 honeypots. Albeit the sheer quantity of it, we will give a short explanation. In addition, Table 3.2 gives a quick overview of all available honeypots in conjunction with (i) the port they are running on, (ii) their interaction level, and (iii) a short description.

ADBHoney [9] is a low interaction Android Debug Bridge (ADB) honeypot over TCP/IP. The importance of it lies in the ADB protocol that is used to debug and push content to an Android device. However, unlike USB it does not support any kind of ample mechanisms of authentication and protection. By exposing the ADB

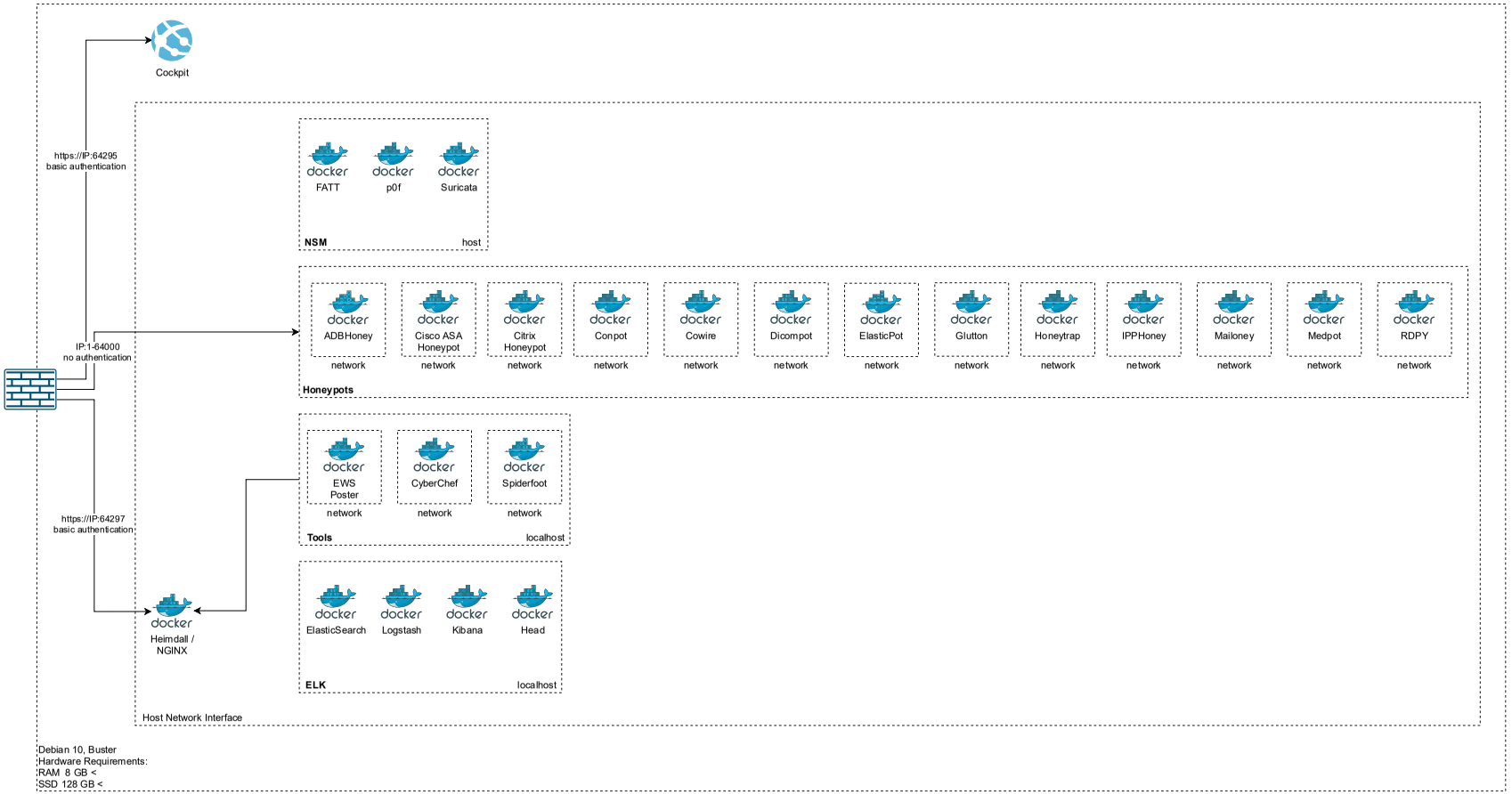


Figure 3.2: T-Pot architecture derived from [52]. Honeypots are encapsulated in their own network. NSM runs on the host network, and thus, receives every packet. ELK and tools run on localhost, and are accessible through NGINX.

service over any port, an adversary could connect and exploit it. ADBHoney is designed to catch malware that has been pushed onto devices.

Cisco Adaptive Security Appliance (ASA) [58] is a low interaction honeypot that detects CVE-2018-0101[17]. It is a vulnerability that could allow an unauthenticated remote attacker to cause a reload of the affected system and to remotely execute code. This can be achieved by flooding a webvpn-configured interface with crafted XML packets. Consequently, the attacker obtain full control by executing arbitrary code.

Citrix Application Delivery Controller (ADC) honeypot [35] detects and logs CVE-2019-19781[19] scans and exploitation attempts. This vulnerability allows adversaries to perform directory traversal attacks. Files are accessible by path strings to denote the file or directory. In addition, some file systems include special character to easily traverse the hierarchy. Attackers take advantage of it by combining special characters in order to get access to restricted areas. [30]

Conpot [59] is a low interaction industrial honeypot for ICS, and SCADA. It provides a variety of different common industrial control protocols. An adversary should be tricked by the complex infrastructure, and lure him into attacks. In addition, a custom human machine interface can be connected to increase the attack surface. By randomly delaying the response time, Conpot tries to emulate a real machine handling a certain amount of load.

Cowrie [53] is a medium to high interaction SSH and Telnet honeypot. It offers to log brute-force attacks and shell interactions with attackers. In medium interaction mode cowrie emulates a UNIX shell in Python, whereas in high interaction mode it proxies all commands to another system.

DDoSPot [23] is a low interaction honeypot to log and detect UDP-based Distributed Denial of Service (DDoS) attacks. It is used as a platform to support various plugins for different honeypot services, and servers. Currently, it supports DNS, NTP, SSDP, CHARGEN, and random/mock UDP server.

Dicompot [42] is a low interaction honeypot for the Digital Imaging and Communications in Medicine (DICOM) protocol. As other honeypots before, it mocks a DICOM server in Go to collect logs and detect attacks.

Dionaea [26] is a medium interaction honeypot that tries to capture malware copies by exposing services. It supports a vast variety of protocols such as FTP, SMB, and HTTP. Several modules can be integrated to work with Dionaea such as VirusTotal for further malware results.

Elasticpot [4] is a low interaction honeypot for Elasticsearch, a search engine based on the Lucene library.

Glutton [60] is a generic low interaction honeypot that works as a MitM for SSH and TCP. However, lacking documentation does not provide a deeper inside of this honeypot.

Heralding [73] is a credential catching honeypot for protocols like FTP, Telnet, SSH, HTTP, or IMAP.

HoneyPy [32] is a low to medium interaction honeypot that supports several protocols such as UDP, or TCP. New protocols can be added by writing a custom plugin for it. HoneyPy should give the freedom of easily deploying and extending honeypots.

HoneySAP [32] is a low interaction honeypot tailored for SAP services.

Honeytrap [77] is a low interaction honeypot network security tool. As stated by Werner [77], Honeytrap is vulnerable to buffer overflow attacks.

IPPHoney [5] is a low interaction Internet Printing Protocol (IPP) honeypot.

Mailoney [47] is a low interaction SMTP honeypot written in Python.

MEDpot [63] is a low interaction honeypot focused on Fast Healthcare Interoperability Resources (FHIR). It is a standard description data format to transfer and exchange medical health records.

RDPY [55] is a low interaction honeypot of the Microsoft Remote Desktop Protocol (RDP) written in Python. It features client and server side, and it is based on the event driven network engine Twisted. It supports authentication over SSL and NLA.

SNARE and TANNER [61, 62] is a honeypot project. SNARE is an abbreviation for Super Next generation Advanced Reactive honEypot. It is a successor of Glastopf, a web application sensor. In addition, it supports the feature of converting existing webpages into attack surfaces. TANNER [62] can be seen as SNARES's brain. Whenever a request has been sent to SNARE, TANNER decides how the response should like.

Tools

T-Pot integrates tools to screen network traffic.

FATT [38] is used to extract metadata and fingerprints such as JA3 [2] and HASSH [39] from captured packets. JA3 is a method for "creating SSL/TLS client fingerprints" whereas HASSH is a "network fingerprinting standard which can be used to identify specific client and server SSH implementations". In addition, it features live network traffic. As noted by the author, FATT is based on a python wrapper for tshark, namely pyshark, and thus having performance downturns. T-Pot applies FATT on every request made on the host network.

Spiderfoot [49] is an open source intelligence automation tool that helps to screen targets to get information about what is exposed over the Internet. It can target different entities such as IP address, domain, hostname or network subnet. In addition, it features more than 200 modules that can be integrated as an extension. T-Pot uses it to scan defensively and thus not include any other module.

Suricata [68] is "a high performance IDS, intrusion prevention system (IPD) and network security monitoring (NSM) engine". T-Pot lets Suricata analyze and assess any request made on the host network.

P0f [79] is a fingerprinting tool that uses passive traffic fingerprinting mechanisms to check TCP/IP communications. T-Pot lets p0f passively check any request made on the host network.

Endlessh [76] is an SSH server that sends an endless, random SSH banner. The key idea is to lock up SSH clients that try to connect to the SSH server. It lowers the transaction speed by intentionally inserting delays. Due to connection establishing before cryptographic exchange, this module does not require any cryptographic libraries.

HellPot [36] is an "endless honeypot". Connecting to this honeypot results in a memory overflow. Its key idea is to send an endless stream of data to the attacker until its memory, or storage runs out.

3.3 Results

Our T-Pot has been deployed for 3 weeks (from 21st of September to 16th of October) and collected in total 607 747 attacks. Overall, RDPY (46.08%), Honeytrap (33.23%), and Cowrie (12.42%) received most of the attacks with a total amount of 540,398 attacks. Figure 3.3 shows the distribution of honeypot attacks. The total numbers are based on Table 3.3.

What is striking is the large disparity between the previously mentioned attacks on AWS, GCP, and Azure. Especially for honeypots like Dionaea, it is unclear why so little attacks have been performed. Therefore, we assume that the packets run through a static filter. Heidelberg itself has a centralized packet filtering which indicates our assumption that certain ports or protocols are excluded. To prove that, a NMAP TCP SYN scan (`nmap -sS -A 129.206.5.74`) has been executed. Our result clearly shows that port 20 reserved for FTP, and port 139 for SMB is filtered, although the access security explicitly allows it. Furthermore, we have checked the stateless firewall that runs in front of heiCLOUD, and it turns out that FTP, SMB like other ports are filtered. Based on this, most of the attacks on Dionaea are made throughout FTP or SMB, and thus, explains the total number of attacks. Moreover, 96% of IP addresses connected to Dionaea are known attackers,

Table 3.2: Overview of all available honeypots and tools of T-Pot with interaction level, port, and a short description. Ports are marked with either TCP or UDP, if a port misses any definition, both TCP and UDP are allowed.

Honeypots	**Port**	**Interaction-level**	**Description**
ADBHoney [9]	5555/TCP	low	ADB protocol honeypot
Cisco ASA [58]	5000/UDP, 8443/TCP	low	honeypot for CVE-2018-0101[17] detection
Citrix honeypot [35]	443/TCP	low	detects and logs CVE-2019-19781[19] scans and exploitation attempts
Conpot [59]	80, 102, 161, 502, 623, 1025, 2404, 10001, 44818, 47808, 50100	low	industrial honeypot for ICS, and SCADA
Cowrie [53]	2222, 23	high	SSH and Telnet honeypot
DDoSPot [23]	1112/TCP	low	log and detect UDP-based DDoS attacks
Dicompot [42]	1112/TCP	medium	honeypot for the DICOM protocol
Dionaea [26]	21, 42, 69/UDP, 8081, 135, 443, 445, 1433, 1723, 1883, 1900/UDP, 3306, 5060/UDP, 5061/UDP	low	capture malware copies
Elasticpot [4]	9200	low	honeypot for Elasticsearch
Glutton [60]	NFQ	medium	MitM proxy for SSH and TCP
Heralding [73]	21, 22, 23, 25, 80, 110, 143, 443, 993, 995, 1080, 5432, 5900	low	credential catching honeypot
HoneyPy [32]	7, 8, 2048, 2323, 2324, 4096, 9200	low	extendable honeypot
HoneySAP [32]	3299/TCP	low	honeypot for SAP services
Honeytrap [77]	NFQ	medium	captures attacks via unknown protocols
IPPHoney [5]	631	low	IPP honeypot
Mailoney [47]	25	low	SMTP honeypot
MEDpot [63]	2575	low	FHIR honeypot
RDPY [55]	3389	low	Microsoft RDP honeypot
SNARE/TANNER [61]	80	low	web application honeypot

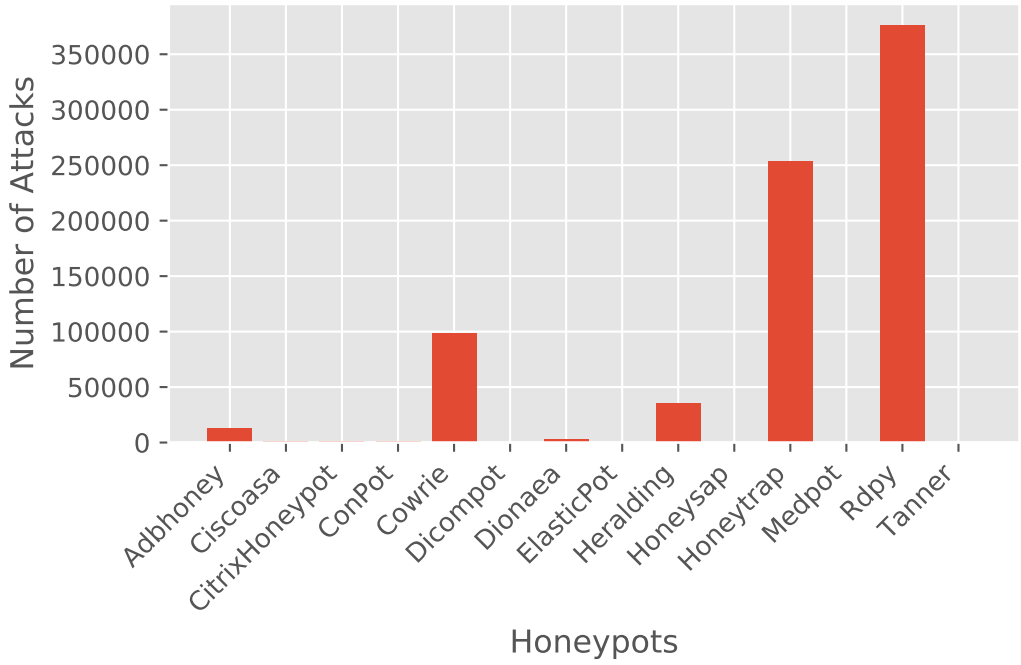


Figure 3.3: Distribution of honeypot attacks

and 70% were acquired on port 81, unofficially known for Tor routing. Neither any malware nor suspicious payload could be identified. Even with an Access Control List (ACL) running in the background, heiCLOUD received more attacks than ever. We assume that the real number might be even higher without any packet filtering for FTP or SMB.

Logstash uses GeoLite2 to resolve the source IP address with information such as location, ASN, continent code, country name, and AS organization. Figure 3.4 indicates the geographical location of connections acquired to any honeypot. Most attacks are originated from the United States, Germany, Russia, and China. Large security scans of DFN or Baden-Württembergs extended LAN (BelWÜ) pushes Germany to second place, therefore, Germany can be considered negligible. On the contrary, the geographical location of an IP address merely indicates the true origin. Due to technologies like VPN or Tor, the last known node of an IP address could be spoofed, and thus as stated by Kelly et al. [41], would remain insufficient to use. Hence, we do not strongly rely on the geographical information.

Attacks are not equally distributed among all honeypots, and thus, different protocols and application receive more attention than others. Figure 3.5 shows the timeline of attacks that are executed on our instance separated by honeypots. RDPY, Honeytrap, and Cowrie are clearly the most attacked honeypots. The high peak of Honeytrap in the middle indicates a full NMAP scan from Germany that

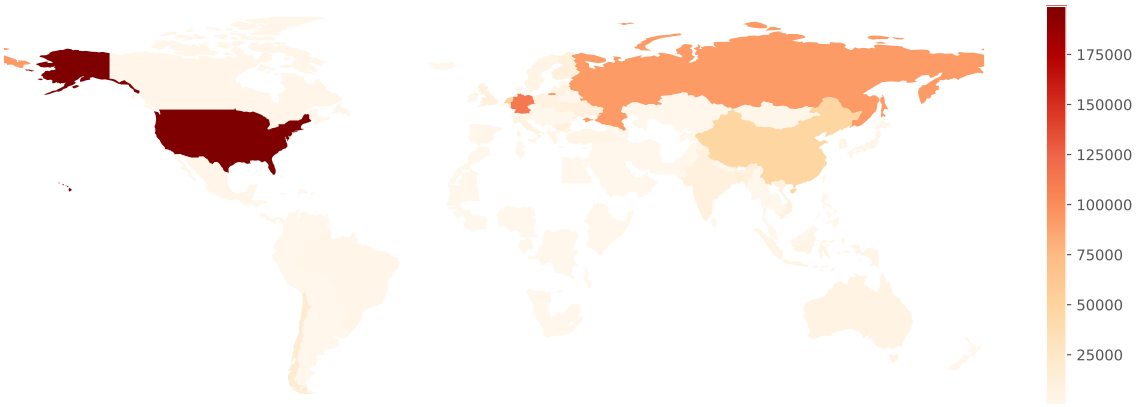


Figure 3.4: Attack distribution of T-Pot. USA, Russia, China, and Germany are the most attacking countries. Timestamp; 21st of September to 16th of October.

has been done to get an inside of the packet filtering at the Heidelberg University. We clearly identify a bias towards remote desktop protocol attacks, shell-code exploitation, and commands to retrieve information about CPU, scheduled tasks (`cat /proc/cpuinfo`, or `crontab`), or privilege escalation.

Suricata registered several alerts and CVE's. The vast majority of alerts are RDP related policies, VNC authentication failures, and NMAP scans. Most used vulnerabilities are (i) CVE-2001-0540[12] which is a memory leak in Terminal servers in Windows NT and Windows 2000 causing a denial of service (memory exhaustion) by malformed RDP requests, (ii) CVE-2006-2369[15] which is a RealVNC vulnerability allowing hackers to bypass authentication, and (iii) CVE-2012-0152[16] which enables attackers for RDP in Microsoft Windows Server 2008 R2 and R2 SP1 and Windows 7 Gold and SP1 to cause a denial of service by sending a series of crafted packets. As derived from Figure 3.6, our T-Pot have not received many attacks in the first week. Starting from 28th of October the numbers of alert are skyrocketing. This would indicate that bots crawl IP address ranges to find new machines and probe them. Interestingly, zero-day exploits like the Apache vulnerability [21] that came with version 2.49.0 got registered in CVE on the 6th of October, and immediately recognized by Suricata on the 15th of October. Attackers could perform a remote code execution using path traversal attacks when the CGI scripts of Apache are enabled. We could trace back similar attacks like `/cgi-bin/.\%2e/\%2e\%2e/bin/sh` until the 7th of October, leaving an even smaller time frame to adapt to new exposures. This shows how fast bots adapt to new vulnerabilities in order to compromise more systems.

The results from RDPY in Figure 3.7 backups our assumption. It shows that only a small margin represents unique src IPs. The rest of the attacks result in either bad reputation, bot, crawler, or known attacker. Figure 3.6 shows the distribution of alert categories that Suricata identified. Respectively, misc activities sum up to

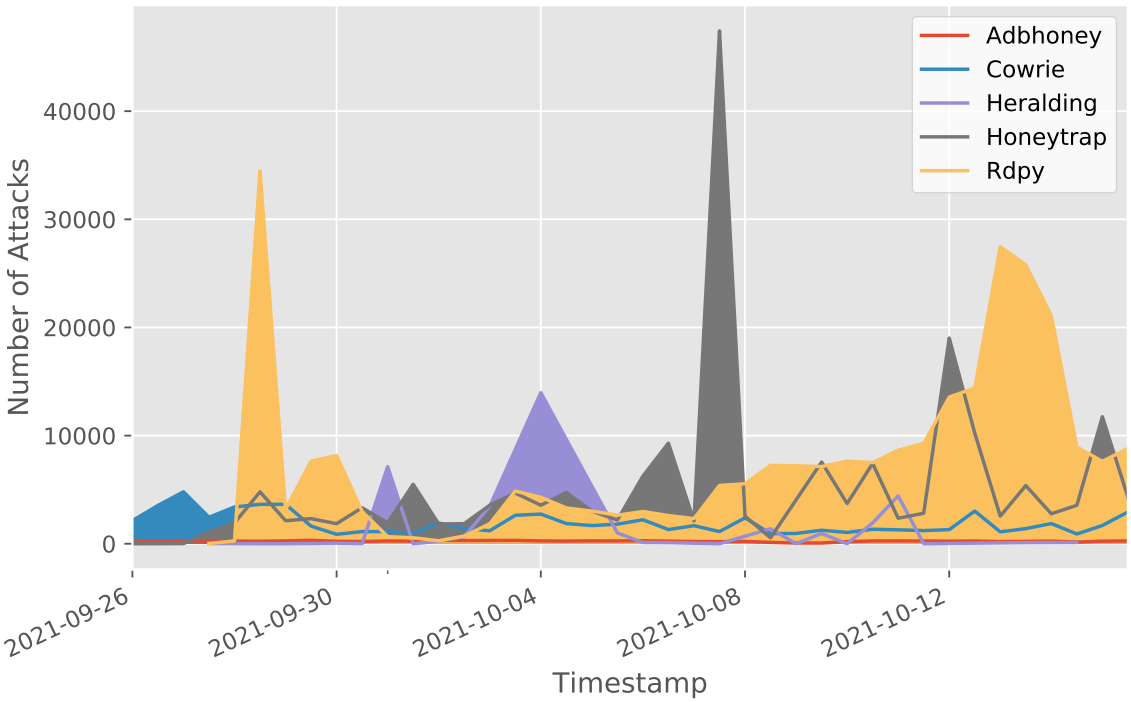


Figure 3.5: Attack histogram of T-Pot. Only the five most attacked honeypots are considered. Timestamp; 21st of September to 16th of October.

roughly 1.5 million entries, RDP related alerts account two-third of it. Several RDP attacks from 2021 back to 2001 had been executed on our T-Pot. Respectively, CVE-2012-0152 and CVE-2001-0540 coincide with the ones Kelly et al. [41] claim. We assume the skyrocketing number of attacks roots back to the Corona pandemic due to an increase of the remote desktop protocol. Furthermore, lack of updates and outdated servers using RDP remain an ease target for automatic attacks that scan the web and try to find new exposures.

For NFQ related attacks, Honeytrap could identify three major services that are not provided by default. Honeytrap functions as a honeypot to provide a service on ports which are not specified by default. NFQ intercepts incoming TCP connections during the TCP handshake and Honeytrap provides a service for it. Most of these interceptions are made on (i) port 5038 which is merely used by a machine learning database called MLDB, (ii) port 5905 which is merely used by an Intel Online Connect Access on Windows machines, and (iii) port 7070 which is merely used by Apple's QuickTime streaming server (RTSP). On nearly all ports attacks focused on RDP connection attempts (`Cookie: mstshash=Administr`). However, 94% of all connected IP addresses are resolved as known attackers.

Third most compromised honeypot is Cowrie with a strong bias towards SSH, and FTP. Figure 3.9 shows all attacks executed on Cowrie separated by their port. Respectively, SSH port 22 is the most considered port, resulting in a high use for

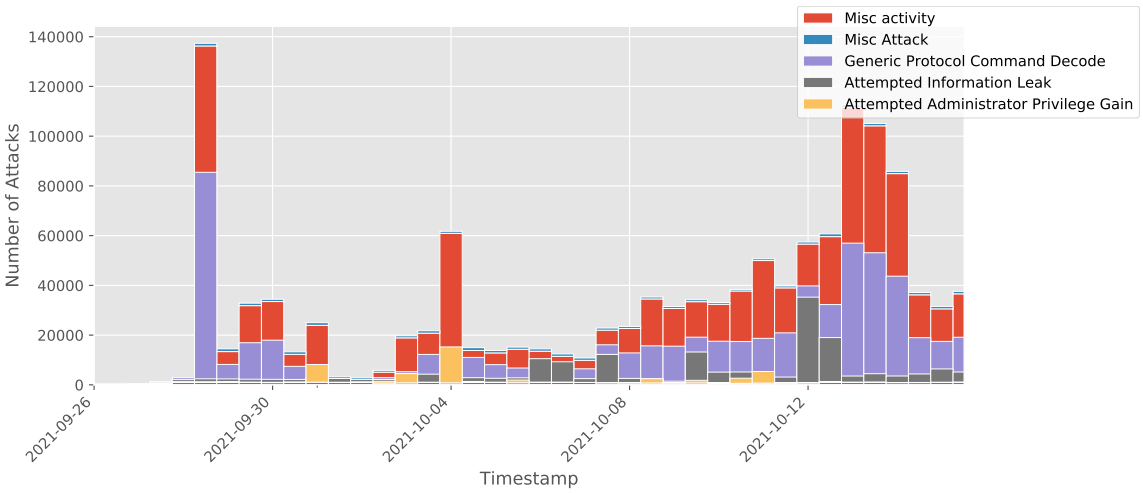


Figure 3.6: Suricata results of T-Pot. Displays the five most listed alert categories. Timestamp; 21st of September to 16th of October.

privilege escalation. Besides default credentials login attempts (`username: root`, `password: root`, see Figure 3.10 for top 10 credentials), adversaries used various commands to retrieve any information about the host system (`nproc;uname -a`, `cat /proc/cpuinfo`). We could identify a unique information gathering attack that has been widely used on our T-Pot. Listing 3.1 shows all shell commands that are executed. Attackers try to gain knowledge about the running process on the system (`/bin/busybox`). Interestingly, crypto mining attacks are getting more attractive to criminals. For example, XMRig has been the most downloaded malware for cryptocurrency mining. Some adversaries even executed complex tailored shell commands to exploit the host machine as a crypto miner (Listing 3.2). With respect to the current time it is not surprising that such attacks gain attraction. Attackers could exploit machines for crypto mining in order to earn more money. This looks more appealing than acquiring mining machines and hijacking electricity from surrounding apartments (Quelle!).

P0f identified different Windows versions and Linux distributions in conjunction with various SSH clients that are used to compromise our T-Pot. Like Kelly et al. [41], Windows 7 or 8 and Windows NT Kernel are the most used OS with 81%. Unfortunately, disguising OS fingerprinting activities account 84% of all fingerprints. Lastly, we cleaned up our results and excluded all IPs from DFN and BelWÜ from our results. Both scan frequently and check if any vulnerability exists. This distorts our findings, and thus, we filtered them based on their subnet addresses. However, the results show no big changes. The total number of attacks were merely influenced by it. This indicates that our own scans do not greatly interfere with our findings. Due to completeness, we leave our results as they are and do not show the filtered data.

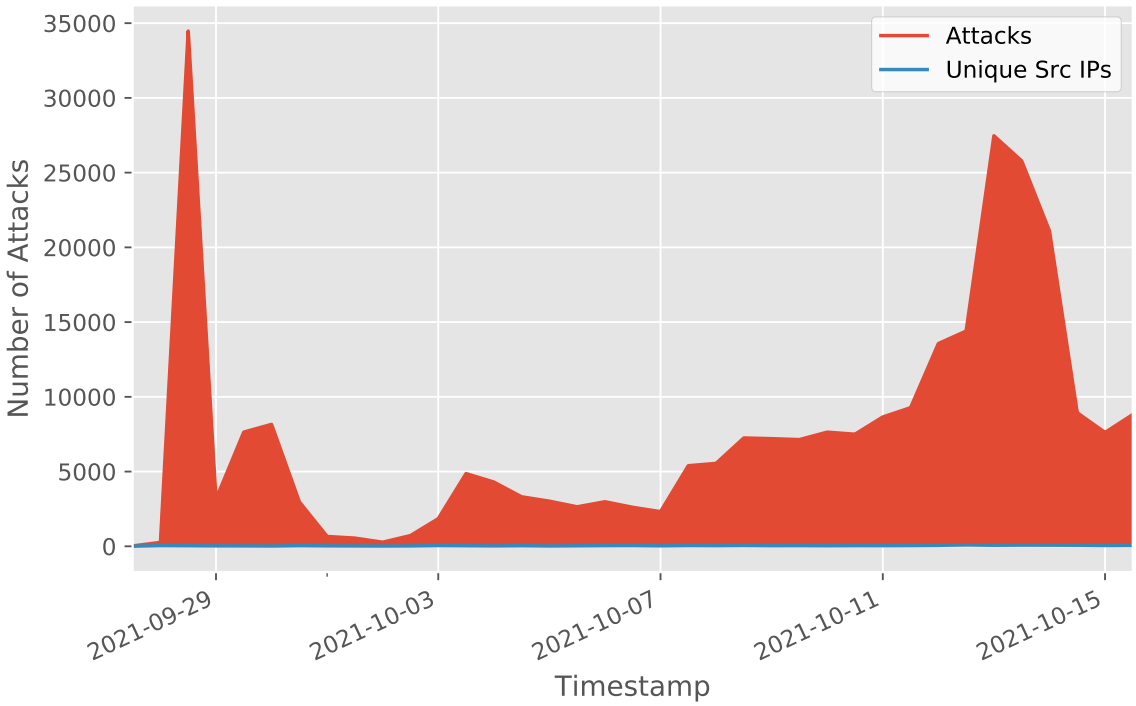


Figure 3.7: RDPY attacks separated in attacks and unique src IPs. Timestamp; 21st of September to 16th of October.

Overall, heiCLOUD receives nearly doubled the size of attacks. On average, heiCLOUD has received 195.31% more than Azure, GCP, and AWS. Attacks on Cowrie, RDPY, and Honeytrap are the most compromised honeypots. In contrast to Kelly et al. [41], Dionaea and Glutton used to be the most considered honeypots for adversaries. We assume that attacks by bots have increased significantly since last year when Kelly et al. [41] did their research. Respectively, one question we are not able to answer is if other cloud providers filter their network traffic. It would explain the major difference between Heidelberg University and the big tech companies. The cause for such an increase remains doubtful. One explanation could root back to the Corona pandemic and the skyrocketing increase in home office activities. Related to that is a higher usage in screen sharing software. Considering the BSI[2] report for cybersecurity 2021 [6], they revealed an increase of attack surfaces during the pandemic. Respectively, the IT infrastructure could not keep up with this fast change and widen the attack surface of the company. Their conclusion overlays our assumption that attackers took advantage and increased their activities. This phenomenon shows that nearly all attacks originate from bots which scan through IP address ranges. In total, 73% of all IP address are unresolved, known attacker reputation represents the largest part of resolved IP addresses with 23%. Fortunately, such reputations could technically be filtered by an organization's firewall

[2]The Federal Office for Information Security is responsible for managing communication security for the German government. Each year they publish a report for recent cybersecurity threats.

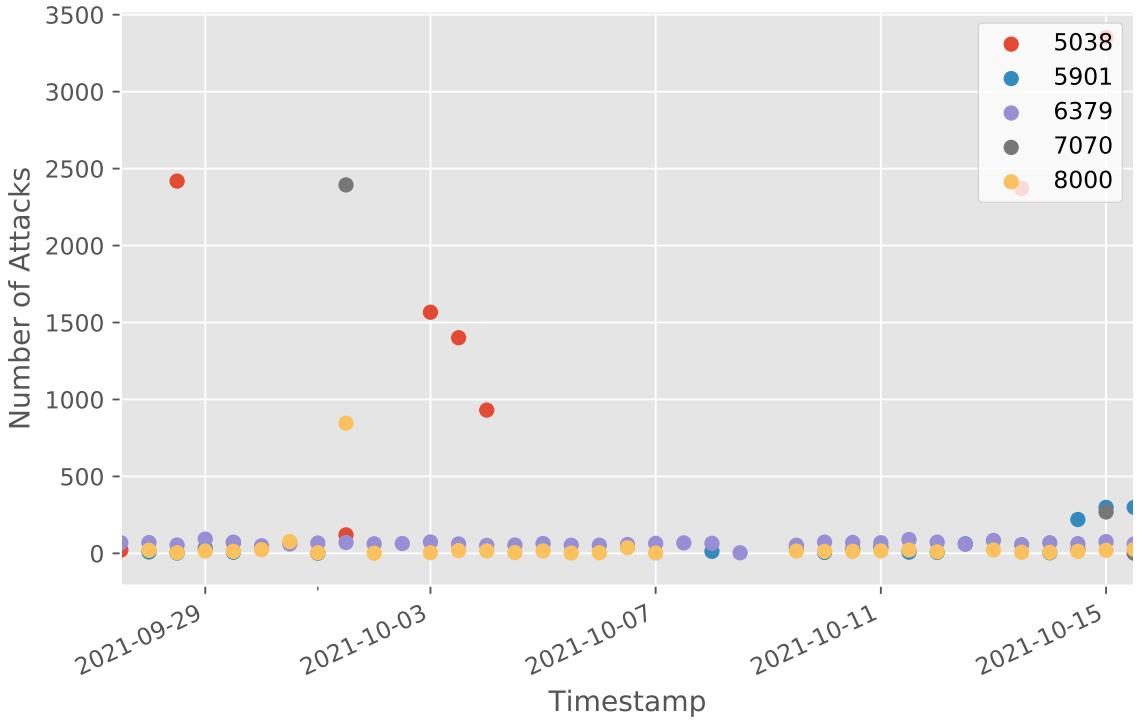


Figure 3.8: Honeytrap results of T-Pot. Timestamp; 21st of September to 16th of October.

and would lower the chance of an exploit. Interestingly, after 3 weeks the number of attacks originated from China decreased to almost zero percent. This might be an indication that our honeypot has been exposed, and further attacks represent a risk of revealing their compromises. However, this assumption cannot be confirmed due to the lax geographical reliability of IP addresses.

Our results lay emphasis on the importance of honeypots. It shows that recent bot activities can be traced to find the newest trends of attacks.

3.4 Discussion

One downside of T-Pot is the static hostname representation of Cowrie. It always returns `#1 SMP Debian 3.2.68-1+deb7u1` (`uname -a`) as hostname information, leaving a tiny footprint when bots crawl through the web. A random choice of hostname information could harden Cowrie from being exposed. Next, if attackers would scan open ports on T-Pot, it might be suspicious when many ports with services are widely open. From a technical perspective, bots could check this state if it is uncommon, and thus, exclude T-Pot from being probed. However, T-Pot includes good preventions like random hostname and scheduled tasks. Another major drawback is the latest endeavor to fingerprint honeypots. As recently investigated

Table 3.3: Overview of attacks on heiCLOUD, AWS, GC and Azure. Only the top 10 most attacked honeypots are considered. "-" entails that a honeypot is not part of the top 10.

Honeypots	BASIS heiCLOUD			COMPARISON AWS		GC		Azure	
	Number	**Pct.**		**Number**	**Pct.**	**Number**	**Pct.**	**Number**	**Pct.**
ADBHoney	9,302	1.65%	↑	413	0.13%	2,497	0.43%	442	0.13%
Cisco ASA	674	0.11%	↑	260	0.08%	750	0.13%	134	0.04%
Citrix honeypot	1,121	0.18%		-	-	-	-	-	-
Conpot	615	0.10%		-	-	-	-	-	-
Cowrie	75,511	11.97%	↓	4,503	1.46%	297,818	51.25%	9,012	2.64%
DDoSPot	0	0%		-	-	-	-	-	-
Dicompot	22	0%		-	-	-	-	-	-
Dionaea	2 368	0.40%	↓	288,075	93.49%	162,570	27.98%	308,102	90.42%
Elasticpot	385	0.06%		-	-	-	-	-	-
Glutton	0	0%	↓	11,878	3.85%	84,375	15.52%	17,256	5.06%
Heralding	35,680	4.34%	↑	1,885	0.61%	12,255	2.11%	3,370	0.99%
HoneyPy	0	0%	↓	172	0.06%	2,149	0.37%	497	0.15%
HoneySAP	15	0%		-	-	-	-	-	-
Honeytrap	201,949	32.01%		-	-	-	-	-	-
IPPHoney	0	0%		-	-	-	-	-	-
Mailoney	0	0%	↓	720	0.23%	9,419	1.62%	146	0.04%
MEDpot	2	0%		-	-	-	-	-	-
RDPY	280,040	49.15%	↑	100	0.03%	7,916	1.36%	1,463	0.43%
SNARE/TANNER	63	0.02%	↓	138	0.04%	1,367	0.24%	313	0.09%
In total	607,747	100%		308,144	100%	581,116	100%	340,735	100%

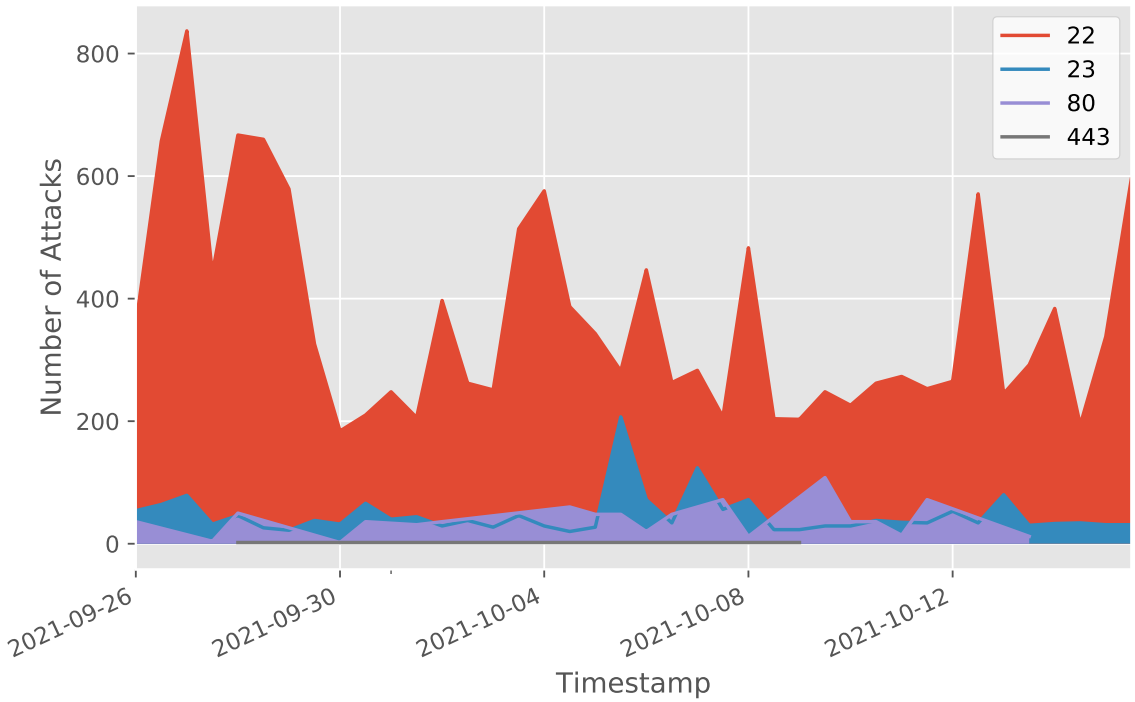


Figure 3.9: Cowrie results of T-Pot. Timestamp; 21st of September to 16th of October.

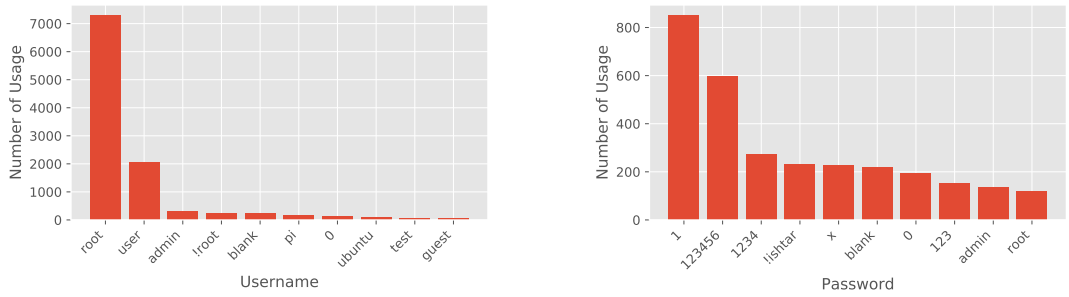
by Vetterl [74], fingerprinting honeypots is becoming easier due to a fatal flaw in the underlying protocol implementation. Vetterl [74] states that attackers always try to prevent their methods, exploits and tools from being divulged. Therefore, detecting honeypots before attack them is a strong motivation for black hats. In chapter 5 we will present a way to avoid fingerprinting of Cowrie.

Listing 3.1: Cowrie attack to gather various information about the system

```
1  enable
2  system
3  shell
4  sh
5  cat /proc/mounts; /bin/busybox $PROCESS_NAME
6  cd /dev/shm; cat .s || cp /bin/echo .s; /bin/busybox
     ↪ $PROCESS_NAME
7  tftp; wget; /bin/busybox $PROCESS_NAME
8  dd bs=52 count=1 if=.s || cat .s || while read i; do echo
     ↪  $i; done < .s
9  while read i
10 /bin/busybox $PROCESS_NAME
11 rm .s; exit
```

Listing 3.2: Cowrie attack to exploit the host machine as a crypto miner

```
1  mkdir -p /home/osmc/.ssh/
2  echo ssh-rsa  $RSA_KEY >> /home/osmc/.ssh//
     ↪ authorized_keys
3  echo '<cmd7uname>'; uname -a
4  echo '</cmd7uname><cmd7uptime>'; uptime
5  echo '</cmd7uptime><cmd7w>'; w
6  echo '</cmd7w><cmd7who>'; who
7  echo '</cmd7who><cmd7last>'; last
8  echo '</cmd7last><cmd7lastlog>'; lastlog
9  echo '</cmd7lastlog><cmd7authkey>'; cat /home/osmc/.ssh//
     ↪ authorized_keys
10 echo '</cmd7authkey><cmd7lshome>'; ls -la /home
11 echo '</cmd7lshome><cmd7passwd>'; cat /etc/passwd
12 echo '</cmd7passwd><cmd7shadow>'; sudo -n cat /etc/shadow
13 echo '</cmd7shadow><cmd7psfaux>'; ps -faux
14 echo '</cmd7psfaux><cmd7netstat>'; netstat -npta
15 echo '</cmd7netstat><cmd7arpan>'; /usr/sbin/arp -an
16 echo '</cmd7arpan><cmd7ifconfig>'
17 /usr/sbin/ifconfig
18 echo '</cmd7ifconfig><cmd7localconf>'; cat /home/ethos/
     ↪ local.conf
19 echo '</cmd7localconf><cmd7remoteconf>'
20 cat /home/ethos/remote.conf
21 echo '</cmd7remoteconf><cmd7rclocal>'
22 cat /etc/rc.local
23 echo '</cmd7rclocal><cmd7claymorestub>'; cat /home/ethos/
     ↪ claymore.stub.conf
24 cat /hive-config/rig.conf; cat /hive-config/wallet.conf
25 cat /hive-config/vnc-password.txt
26 echo '</cmd7claymorestub><cmd7claymorezstub>'
27 cat /home/ethos/claymore-zcash.stub.conf
28 echo '</cmd7claymorezstub><cmd7sgminerconf>'
29 cat /var/run/ethos/sgminer.conf
30 echo '</cmd7sgminerconf><cmd7iptables>'
31 sudo -n iptables -S  && sudo -n iptables -t nat -S
32 echo '</cmd7iptables><cmdcrontab>'; crontab -l; echo '</
     ↪ cmdcrontab>'
33 exit
```



(a) Cowrie username credentials

(b) Cowrie password credentials

Figure 3.10: Cowrie top 10 credentials used on T-Pot. Timestamp 22nd of September to 18th of October

Chapter 4

Catching Attackers in Restricted Network Zones

Our T-Pot identified a flood of threads when it was widely available on the Internet. However, capacious networks do have separated compartments and usually services are not directly available without any protection. Zoning is a well-known method to segment a network. Heidelberg University applies zoning, and thus, it is an interesting question if any attacker probes services outside or within the network. To detect any dubious packets in the network we present a concept using a honeypot-like detection tool. We show that attacks in a restricted network zone of the Heidelberg University's internal network occur, and contributed to an adaption of the stateless firewall. Thus, improving the security of the network.

4.1 University Network

Honeypots that are accessible via the Internet do receive a broad range of attacks. As Spitzner [66] noted, a honeypot is not strictly bound to run in a demilitarized zone (DMZ) or in a network with direct Internet access. The correct location has to be chosen based on the goals of the honeypot. For example, one goal could be to catch attackers behind a perimeter firewall to reveal leaks or vulnerabilities. Beforehand, our honeypot was broadly available on the Internet, and attackers could probe it easily. It collected on average 55 000 attacks per day, resulting in a total amount of 786 564 attacks. Zoning a network into logical groups mitigates the risk of an open network. Thus, our T-Pot would receive significantly fewer attacks in a controlled network zone. A network infrastructure is segmented into the same communication security policies and security requirements. For example, the Canadian government created their own baseline for infrastructures, called Baseline Security Architecture Requirements for Network Security Zones in the Government of Canada (ITSG-22). The four most common zones are: (i) Public Zone (PZ) which is entirely open, (ii) Public Access Zone (PAZ) which interacts as an interface between the PZ and

internal services, (iii) Operations Zone (OZ) which processes sensitive information, and (iv) Restricted Zone (RZ) including business critical services. A network zone restricts access and controls data communication flows. [11]

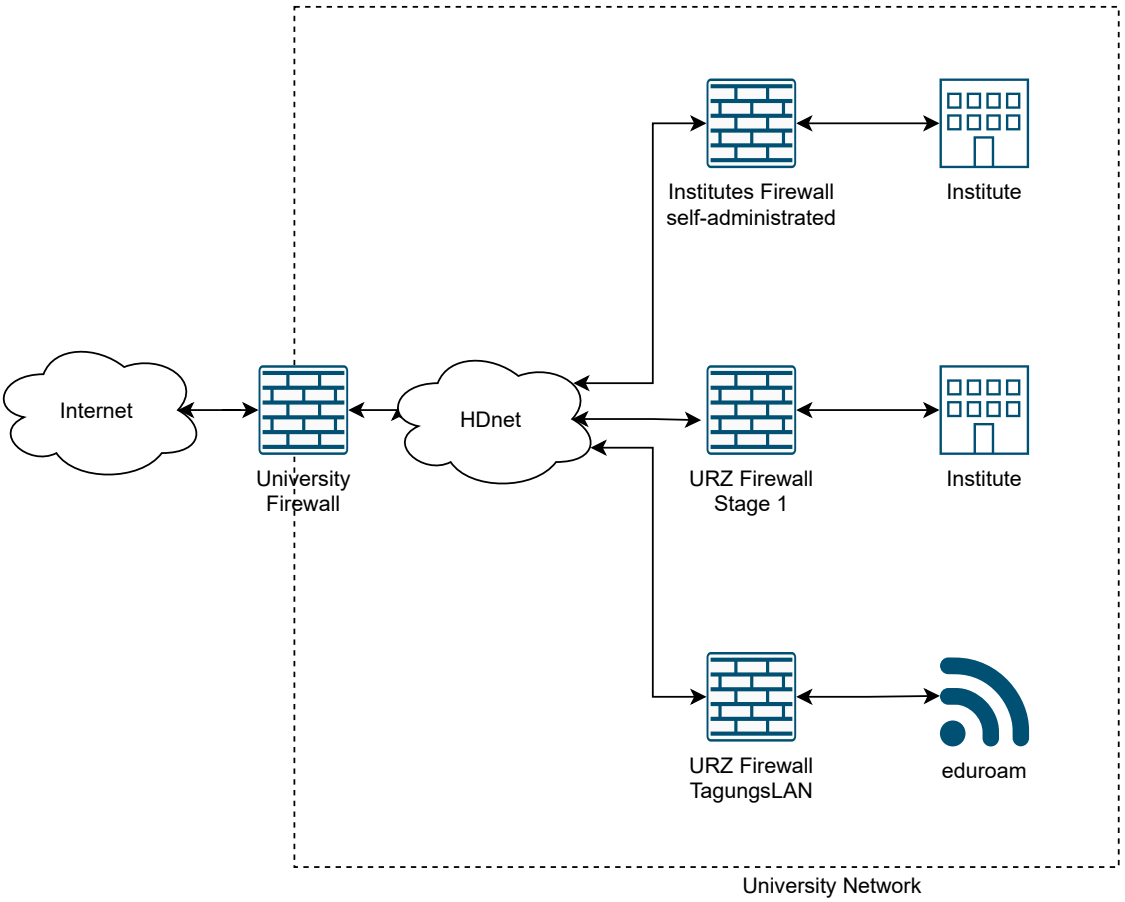


Figure 4.1: Draft of the University network. The URZ firewall represents the stateful firewall. The "TagungsLAN" i

The network at the Heidelberg University includes a central stateless firewall (ACL) that enfolds all institutes. It entails a default blacklist that blocks certain services such as SMTP, NCP, or SNMP, and a stateless filter provided by BelWÜ. Inside the network, each institute has the possible to either use a pre-defined stateless firewall provided by the University Computing Center Heidelberg, or use a self-administrated firewall. Figure 4.1 outlines the association between these components. The internal "HDnet" enables the communication between institutes without leaving the internal network. Institute firewalls can be set up by each institute and is self-administrated. They do have the possibility to use Small Office Home Office (SOHO) routers[1] to disconnect certain network zones from the network. It is recommended to configure the global ACL as a fall back solution in case of any downtime.

[1]SOHO router is a broadband router used in small offices and home offices environments.

Table 4.1: Overview of firewall stages at the University Heidelberg. As an example we applied the rules to subnet `129.206.218.0/24`. Any rule does apply to any another subnet.

Name	Description	range
Stage 0	Filters broadcast communication	`129.206.218.0-15/24`
	No filtering	`129.206.239.16-255/24`
Stage 1	Allows common network protocol	`129.206.239.0-255/24`
	Allows services	`129.206.239.240-255/24`
Stage 3	Internet access only via internal proxies	`129.206.239.0-255/24`
Stage 4	Only internal network communication	`129.206.239.0-255/24`

The University Computing Center Heidelberg offers stateless firewall for router interfaces or VLANs. This stateful firewall whitelists certain services and splits up into four stages. Each stage can be individually activated per router interface. Its key value is to maintain a baseline security to avoid any misconfigurations and port scans. Table 4.1 outlines these stages including the IP address range. Before applying one of these zones, the respective network has to oblige to client IP addresses below `129.206.218.240/24`. In addition, `129.206.218.1` is allocated for the gateway. A network has to adhere to these obligations if it applies any of these pre-defined stages.

An interesting question is if attackers have access to restricted zones at the Heidelberg University. It arises during the research of T-Pot if an adversary would try to probe any hosts in the internal University network. In order to detect such events we present honeypot-like packet detection application that helps to identify any threats in a network. In addition, it offers to deploy multiple instance and collect their data in a centralized instance.

4.2 Honeypot-like Connection Detection Tool

Recording and investigating connection attempts assimilates new honeypots. Respectively, we will present a new honeypot-like detection tool called MADCAT. It has been developed by the BSI, and helps us to log any connection attempt being made on our host machine. The acronym MADCAT stands for Mass Attack Detection Connection Acceptance Tools. It works as a honeypot-like detection application with low interaction level. Its key idea is to log every connection attempt and further process it to retrieve credentials, or shell exploitation. Figure 4.3 gives an inside how MADCAT works. It runs on an Ubuntu distribution either 18.04 or 20.04. We have

tested it on Ubuntu 18.04. It processes packets from any interface that has been configured. As an example, we could process Ethernet and wireless packets. MADCAT itself consists of six independent modules for TCP, UDP, ICMP, and RAW packets that communicating with each other through a pipeline. A module is responsible for analyzing packets and logging the results in a queue. In addition, UDP and TCP offers a proxy to tunnel packets to another service. TCP postprocessor reads every 5 seconds the newly arrived TCP packets and processes them accordingly. It resolves packets to log data including source IP address, protocol and event type. The enrichment processor is the final process step. Its purpose is to log all written packets of the queue in a specified format for further analyzation. The key idea of MADCAT is to get an inside if attackers have access to a certain network. In contrast to T-Pot, we do not want to know what specific attacks are operated on our honeypot. Instead, we do want to ensure that no one else than authorized users have access. Especially in high confidential areas, no attacker should be capable of sending even a single packet to a host in the network. Tracking packets on a detailed level is not provided by the vast range of honeypots.

In addition, we will deploy a T-Pot instance to have comparison data to our new concept. We focus on the `129.206.218.0/24` and `147.142.0.0/16` subnet. The `129.206.218.0/24` subnet is used within University Computing Center Heidelberg building. Every client in the building has a compelling connection in this subnet. Otherwise, an Internet connection would not be feasible. The subnet `147.142.0.0/16` connects clients to "eduroam"[2]. Like the four stages of the institute firewall, the "eduroam" network, also called "Tagungslan", builds various permits into the subnet. One essential difference is that services like SMTP and HTTP are not allowed, so that, attackers are not able to deploy traps for users. Moreover, each client is encapsulated in its own subnet that disables any communication to others clients. Our instances are located in the building with IP addresses `129.206.219.65` and `129.206.219.88`. Figure 4.2 outlines our concept using MADCAT and a separate instance to visualize our data. The first instance with IP address `129.206.5.157` provides Kibana, and Elasticsearch to visualize and crawl logs. The honeypot with IP address `129.206.5.88` consists of MADCAT in conjunction with P0f, Suricata, and FATT. Like T-Pot, we use Logstash to forward our data to Elasticsearch. One benefit is the centralized approach to store data. This allows to randomly deploy more instances to collect data from other zones.

4.3 Results

Our MADCAT (28th of October till 17th of November) and T-Pot (16th of November till 6th of December) have been deployed for three weeks respectively. All instances had a connection to both subnets. First, the results obtained in the subnet

[2]The eduroam is an international Wi-Fi internet access point for researchers.

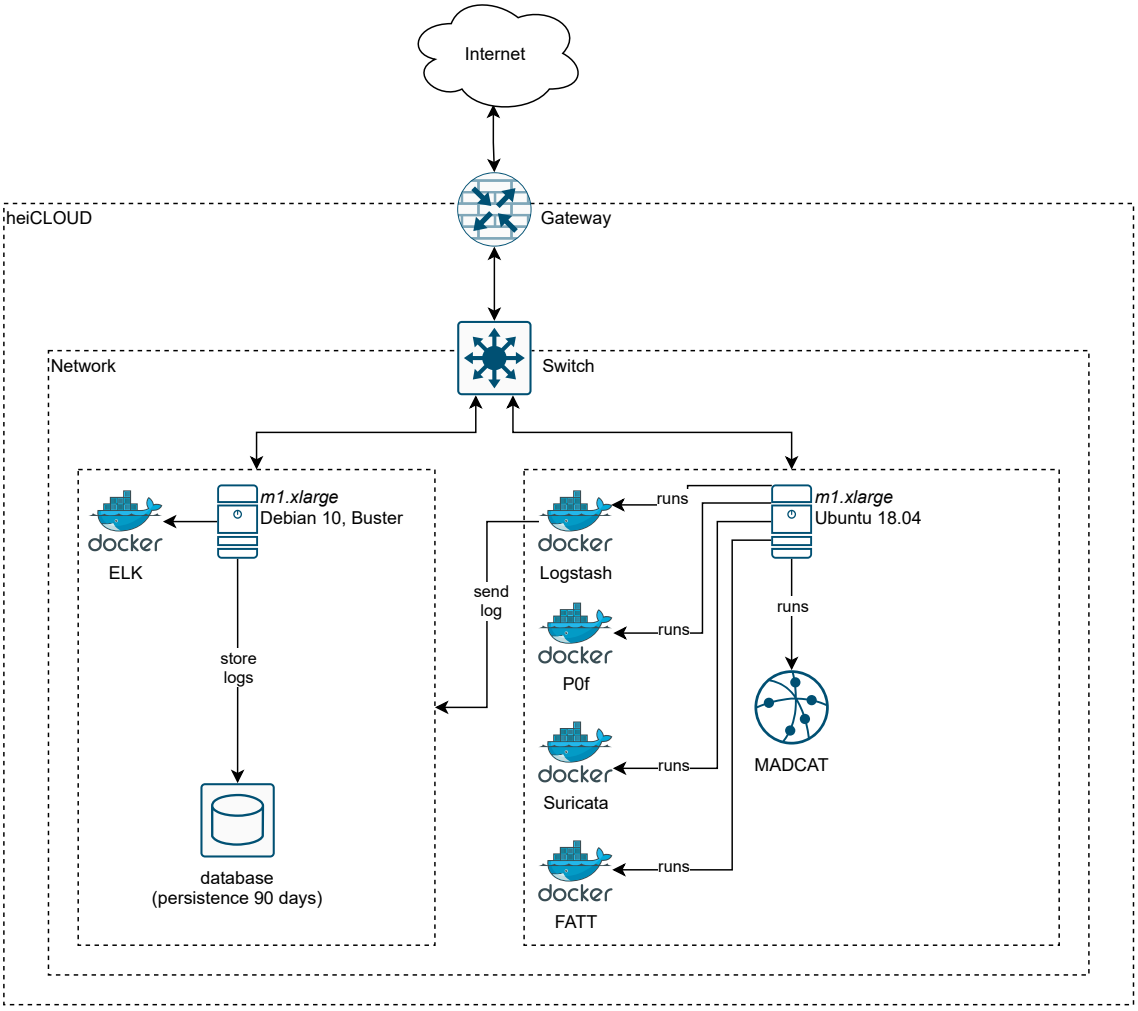


Figure 4.2: Concept to detect connection attempts. Kibana and Elasticsearch are deployed in heiCLOUD.

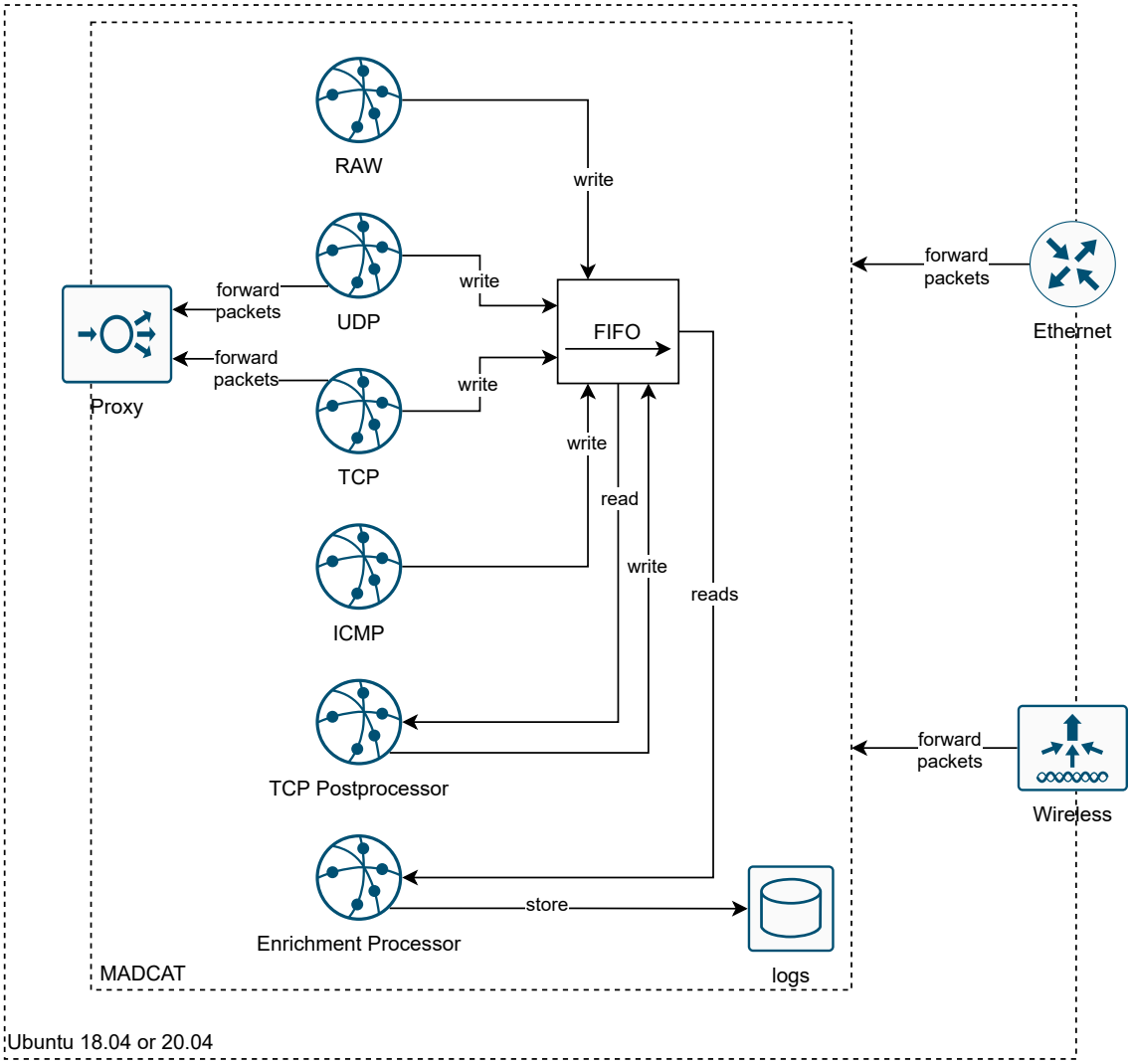


Figure 4.3: Visualization of the MADCAT packet flow starting at the network interface. The Ethernet and wireless interface forwards packets to the desired module.

`129.206.218.0/24` will be presented, closing up with the ones we claim in the eduroam network.

In total, MADCAT received 35 372 packets. Overall, the modules TCP (66.62%) and RAW (33.26%) received the majority of all connection attempts. The minority with less than one percent are suspicious packets which have individual TCP flags like reset or syn set. On contrary, we could not identify any harmful activity based on these packets. In addition, the T-Pot accounted in total . Overall, ConPot (), Honeytrap (), and Ciscoasa () received most of the attacks with a total number of 1. Interestingly, we could identify Simple Network Management Protocol (SNMP) connections which are used by print servers to discover printers.

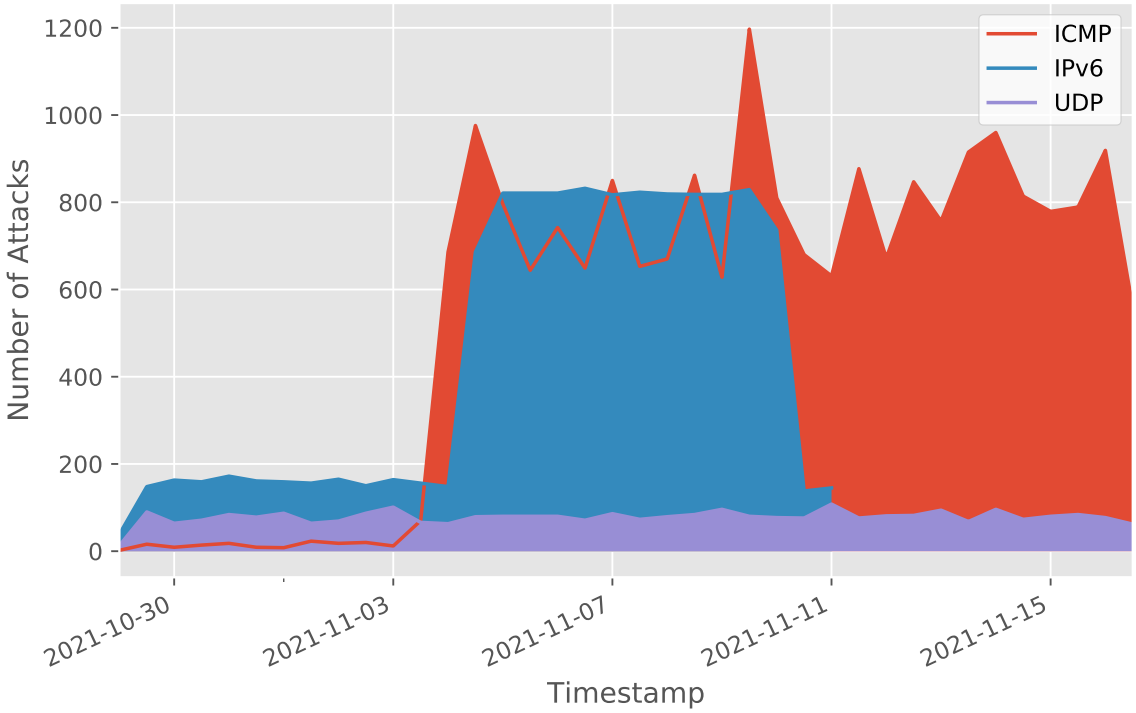


Figure 4.4: Protocol distribution of MADCAT. ICMP, IPv6 and UDP are the most used protocols. Timestamp; 28th of October to 17th of November.

Figure 4.4 shows the protocol distribution indicating a high amount of ICMP and IPv6 packets. Only 11.59% of all IP address reputations could be resolved, splitting up into known attacker (11.26%), mass scanner (0.14%), bad reputation (0.12%), and tor exit node (0.08%). Focusing on TCP packets, 88.3% are known attackers with source port 113 as main target. The port 113 is officially known as the Identification Protocol (IDENT)[37] used for identification/authorization on a remote server such as POP, IMAP, and SMTP. Comparing the results with the stateless firewall settings, we spot a potential leak that allows adversaries to send IDENT requests to our network. Decoding the payload of these TCP packets, rather than compromising systems based on IDENT protocol vulnerabilities attackers used this

port to deploy any exploitation attempt possible. We identified attempts to acquire an SSH session, using SMB and SIP connection attempts, as well as various HTTP requests. For an example we take a closer look at two payloads that have been sent to our instance. Listing 4.1 outlines an SIP probe that checks if any VoIP service is active by answering the request packet. Next, Listing 4.2 shows an SMB probe trying to achieve the same. The IP address reputation could help to answer if these packets are sent by a real user or an attacker. Considering our two examples, both IP addresses were resolved as known attacker, thus, we identified them as a probe packet before executing their attack. A vital security interest in port 113 is negligible, however, our concept helps to detect such leaks especially when stateless firewalls are the main doorkeeper for packets.

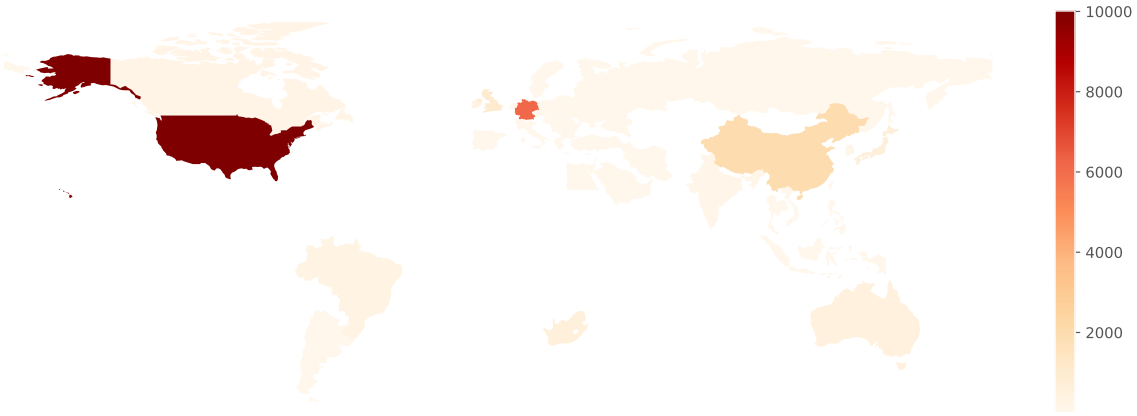


Figure 4.5: Attack distribution of MADCAT. USA, Russia, China, and Germany are the most attacking countries. 28th of October to 17th of November.

Figure 4.5 shows the attack distribution indicating the origin of an IP address. Most of the connection attempts are originated from the United States, Germany, and China. As we have shown beforehand in chapter 3, geographical information only outlines the last know location of a node. Like our results in heiCLOUD, we assume that this information is not reliable as an indicator from where attacks take place. Nevertheless, it is an interesting inside to see where the last node originated from.

Suricata identified odd behaviors in the network (Figure 4.6). In total, it detected 300 000 alerts and CVEs. Besides minor alerts like NMAP scans, Suricata registered alerts in SNMP requests, TCP stack, and Wind River VxWorks. CVE-2020-11899 [20] accounts nearly 99% with a total number of 102,838. This CVE is one of 19 others forming the "Ripple20" vulnerability in the low-level TCP/IP library developed by Treck, Inc.. One of the task of the Track TCP/IP stack is to reassemble fragmented packets. Whenever a fragmented packet arrives the stack tries to validate to total length in the IP header. If the total length is not correct, it trims the data. However, this leads to an inconsistency, and thus, resulting in a buffer overflow when someone sends fragmented packets through tunnel. A detailed de-

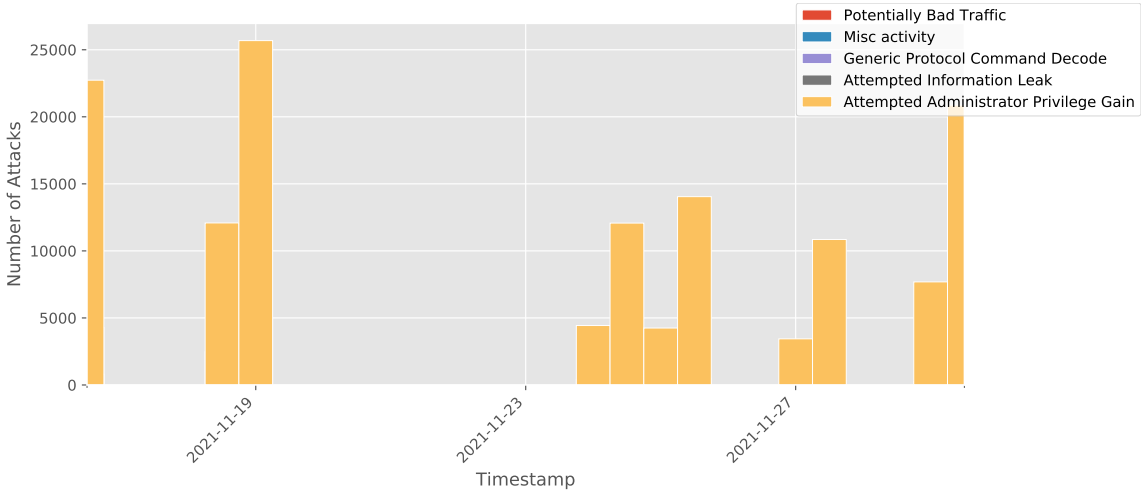


Figure 4.6: Suricata results of T-Pot. Timestamp; from 16th of November to 6th of December

scription of the vulnerability can be found in [43]. Adversary could send malformed IPv6 packets that cause an Out-of-bounds Read which results in a potential remote code execution. Only TCP/IP stack versions until 6.0.1.66 are affected by this vulnerability. Nevertheless, the tremendous amount of alerts shows the importance of adapting the IPv6 permits. Second most recorded vulnerability with the highest score is CVE-2002-0013 [13] that allows remote attackers to cause a denial of service or gain privileges in the SNMPv1 protocol. The root cause for the CVE alert is the usage of the default public community for broadcast requests instead of configuring a private community with mandatory authentication. To compromise SNMP, attackers have to have access to the protocol. However, the University firewall blocks SNMP port 161 and 162 for TCP and UDP, thus, restricting any access from outside. If adversaries plan to deploy an attack on the SNMP protocol, they need to have a connection to the internal network. Acquiring a connection to the internal network at University seems to be rather hard to accomplish. On the contrary, all connection attempts registered by our concept have been made within network, and they do reflect a normal SNMP communication. Lastly, Wind River VxWorks 6.9.4 and vx7 in CVE-2019-12263 [18] cause a Buffer Overflow due to the underlying TCP component that results in a race condition. Each connection attempt with CVE-2019-12263 originated from Russia. Hence, we assume that the source IP address had a vicious intention to send an urgent flag. However, for the other CVE's the IP reputation could not be resolved.

Results from our T-Pot instance are exiguous, and in short, no real attacks such as shell exploitation have been performed. Overall, all connection attempts originated from Germany within the same network, and are made on port 161 and 4567. Conpot registered minor SNMPv2 Get, SNMPv1 Get, and GetNext requests. A possible attack vector could be an SNMP reflection/amplification attack. As previ-

Listing 4.1: MADCAT connection attempt to exploit SIP connection. Received on the 16th of November. IP reputation: known attacker. Location Germany.

```
1 OPTIONS sip:nm SIP/2.0 Via: SIP /2.0/TCP nm;
2 branch=foo From: <sip:nm@nm>;
3 tag=root To: <sip:nm2@nm2> Call-ID: 50000 CSeq: 42
    ↪ OPTIONS Max-Forwards: 70 Content-Length: 0 Contact:
    ↪ <sip:nm@nm> Accept: application/sdp
```

Listing 4.2: MADCAT connection attempt to exploit SMB connection. Received on the 16th of November. IP reputation: known attacker. Location Germany.

```
1 PC NETWORK PROGRAM 1.0 MICROSOFT NETWORKS 1.03 MICROSOFT
    ↪ NETWORKS 3.0 LANMAN1.0 LM12X002 Samba NT LANMAN 1.0
    ↪ NT LM 0.12.
```

ously discussed our assumption is that devices within the network have a misconfigured printer and send broadcast requests frequently to find the machines. These SNMP requests affiliate with day-to-day traffic in an internal network, and thus, are not suspicious. Second most attacked honeypot is Honeytrap which received numerous packets on different ports whereas 39% evince an empty payload. All of these received packets have a resolved IP address in the subnet `129.206.0.0/16`. It remains unclear if these connections are malicious or are acquired by accident. Investigating the payload of outliers does not confirm the assumption of a vicious intention. Thus, declaring these results as negligible. Overall, most of the connection attempt received by our instance are from these IP addresses: `129.206.217.118`, `129.206.218.23`, and `129.206.218.194`.

Lastly, we consider the results from the eduroam network. Neither T-Pot nor MADCAT could identify any significant behavior over a period of three weeks. Unlike the subnet `129.206.218.0/24`, our honeypot did not register any suspicious packets, TCP flags, or other CVEs. In retrospect, the eduroam configuration has shown to work as designed. Thus, our client seemed to be encapsulated from others, and receives no other packets.

Besides the subtle output we have received, our results have given an inside of the value of honeypots in a restricted network zone. For the Heidelberg University, using honeypots to evaluate their stateless firewall have never been considered. We have shown that our initial concept delivered minor findings in the subnet `129.206.218.0/24` with stage 1 firewall. As a result the port 113 used for the IDENT protocol will be removed in the future to reduce the attack surface, thus, contributing to the firewall definition. Overall, our two instances received numerous

packets containing interesting payloads. In comparison to our T-Pot that has been deployed in heiCLOUD, our results are as expected delicate and the data analyzation results in a more detailed manner. The statement from Spitzner [66] that honeypots only receive little input and nearly ever input is suspicious matches our results only half way. As shown beforehand, our results are dramatically little, however, only a few requests seemed suspicious. Nonetheless, we could answer our initial question if attackers have any access to the restricted network zone at the Heidelberg University.

4.4 Discussion

We have seen that honeypots do help to find potential leaks in restricted network zones. However, it remains questionable if our concept is capable of delivering correct results. Our instance has been running for three weeks in the subnet `129.206.5.0/24`. However, to deliver any meaningful entries our honeypot needs to be detected as vulnerable target. We could not detect any large scans on our instance, thus, it is very likely that either an attacker could not find our instance or no one had any kind of access.

Chapter 5

Mitigate Fingerprinting of Honeypots

Detecting honeypots before launching attacks helps to avoid disclosure of information. In chapter 3, we have seen that bot activities are on the rise, and more attacks are launched than ever. However, many identical attacks could be identified. In this chapter, we will conduct two experiments related to this question. First, we want to reproduce the findings that Vetterl [74] claims to proof . Lastly, we want to disguise Cowrie with the idea we have mentioned beforehand.

5.1 OpenSSH

OpenSSH is one of the most used applications that helps to acquire an SSH connection. Before proceeding with generic weaknesses of honeypots, we want to give a short intermezzo about OpenSSH itself.

OpenSSH consists of three major layers, namely `ssh-connection`, `ssh-userauth`, and `ssh-transport` (Figure 5.1). Last layer is the most important one because it provides the basic functionalities for crypto operations such as the key exchange and encryption.

The first layer is responsible for authenticating the user to the sshd daemon. Based on two-way authentication, the client authenticates the sshd daemon by the help of the `ssh-transport`. Finally, a secure connection is established, and the key exchange is done. Next step is to authenticate the user of the client. It offers various authentication methods such as username/password, public key, or smartcard authentication. If the `ssh-userauth` layer is successful, it will establish a secure channel through the `ssh-connection` layer. Each session is handled in a so-called channel.

The `ssh-connection` layer handles multiple sessions simultaneously over a single `ssh-userauth` layer with the TCP/IP layer below. It is responsible for executing

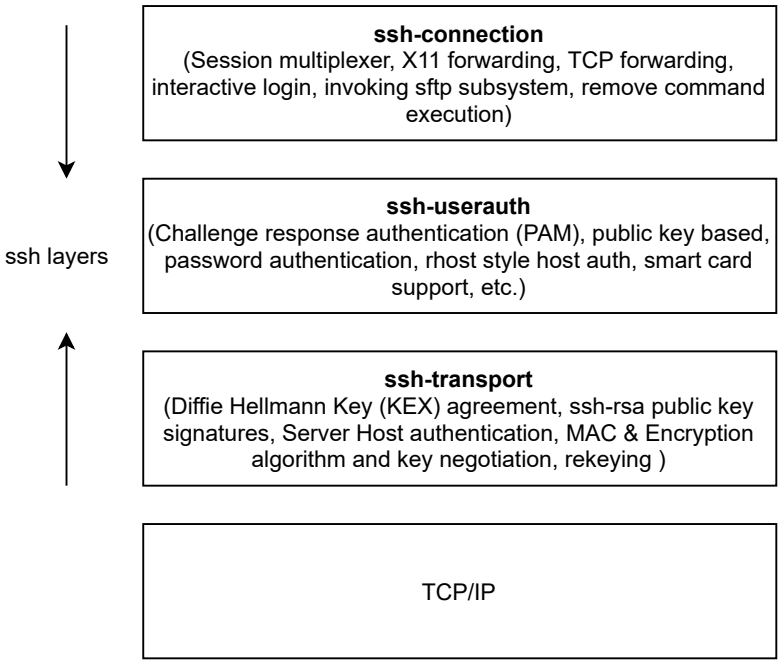


Figure 5.1: OpenSSH architecture (derived from [72])

arbitrary commands, forwarding X11 connections, establishing VPN tunnels and more.

In addition, OpenSSH comes with built-in features such as keep alive messages, redirecting stdin to /dev/null for specialized X11 windows.

Figure 5.5 outlines a sample session between a client and a server. The key exchange initialization is the first message between them to negotiate all ciphers and keys for communication. For this chapter, no other than this message will be considered.

5.2 Preliminary Work

Attackers have a strong motivation to reveal honeypots before launching an attack. Without any protection attackers would disclose their methods, and thus, newly developed attacks would become useless. As shown in chapter 3, attackers do try to get information about the host system. Vetterl [74] discussed various methods of fingerprinting, however, executing commands in a login shell and examining the response leaves precarious information to the honeypot itself. In his work he evaluated methods to detect honeypots at the transport level. As stated, the value of a honeypot would be merely zero if a detection on transport level would work. He presents fingerprinting methods for SSH, Telnet, and HTTP/Web. Due to the complexity of each method, we focus on SSH fingerprinting with the honeypot Cowrie. The idea to detect SSH honeypots is to look for deviations in the response. Therefore,

Vetterl [74] sends a set of probes $P = \{P_1, P_2, \ldots, P_n\}$ to a given set of implementations of a network protocol $I = \{I_1, I_2, \ldots, I_n\}$ and stores the set of responses $R = \{R_1, R_2, \ldots, R_n\}$. For the given set of responses he calculated the cosine similarity coefficient C. Goal is to find the best P_i where the sum of C is the lowest. Figure 5.2 presents these steps.

Cosine similarity outputs the similarity between vectors of numerical attributes. In text semantics it is widely used to measure the similarity of sets of information such as two sentences. Vetterl [74] outlines that it can be used in "traffic analysis to find abnormalities and to measure domain similarity". Mathematically, it computes the angle between two vectors. For each set of information A, we create a vector D_A. Referring to our use case with SSH, we use the response from the server as information A. If θ is the angle between D_A and D_B, then:

$$\cos\theta = \frac{D_A \cdot D_B}{\|D_A\|\|D_B\|} \tag{5.1}$$

where "$\cdot$" is the dot product obtained by:

$$D_A \cdot D_B = \sum_{i=1}^{n} (D_{A_i} \times D_{B_i}) \tag{5.2}$$

and $\|D_A\|$ (resp. $\|D_B\|$) is the Euclidean norm, obtained by $\sqrt{\sum_{i=1}^{n} D_{A_i}^2}$ (resp. $\sqrt{\sum_{i=1}^{n} D_{B_i}^2}$). The values of vectors are non-negative. The similarity between items is the value $\cos\theta$, $\cos\theta = 1$ indicates equality.

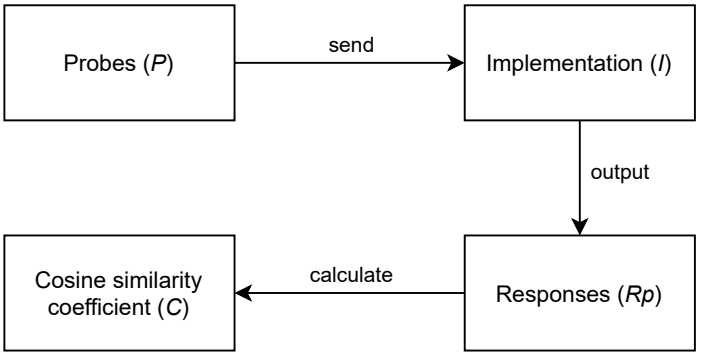


Figure 5.2: Outline to obtain the cosine similarity coefficient (derived from [74]).

In order to find the best P_i for SSH, Vetterl [74] first created different SSH version strings based on the format: `SSH-protoversion-swversion SP comment crlf`. He

Listing 5.1: OpenSSH connection attempt with probed SSH packet. All non-essential debug information have been removed to lay emphasis on the modified key exchange initialization.

```
1 Local version string SSH-2.2-OpenSSH
2 SSH2_MSG_KEXINIT sent
3 SSH2_MSG_KEXINIT received
4 kex: algorithm: ecdh-sha2-nistp521
5 kex: host key algorithm: ssh-dss
6 kex: server->client cipher: blowfish-cbc@openssh.com MAC:
    ↪ <implicit> compression: zlib@openssh.com
7 kex: client->server cipher: blowfish-cbc@openssh.com MAC:
    ↪ <implicit> compression: zlib@openssh.com
```

used different lower and upper case variations, 12 different protoversions ranging from 0.0 to 3.2, swversion set to "OpenSSH" or empty string, comment set to "FreeBSD" or empty string, and crlf to either `\r\n` or empty string. In total, summing up to 192 client version strings. Second, he created different `SSH2_MSG_KEXINIT` packets with 16 key-exchange algorithms, 2 host key algorithms, 15 encryption algorithms, 5 MAC algorithms and 3 compression algorithms. In total, he sent 58 752 `SSH2_MSG_KEXINIT` packets. Combining them with the 192 client versions, he ended up sending 157 925 376 packets. The version string `SSH-2.2-OpenSSH \r\n` and the `SSH2_MSG_KEXINIT` packet including ecdh-sha2-nistp521 as key-exchange algorithm, ssh-dss as host key algorithm, blowfish-cbc as encryption algorithm, hmac-sha1 as mac algorithm and zlib@openssh.com as compression algorithm, with the wrong padding result in the lowest cosine similarity coefficient C. Listing 5.1 shows the SSH debug information with the modified version string, and key exchange message.

Table 5.1 has been derived from Vetterl [74] to present his results of the cosine similarity of OpenSSH, Twisted, and Cowrie. Twisted has been added to have an example with an older SSH honeypot. We can see that it differs fundamentally from OpenSSH. At most, it scores 0.52 whereas various OpenSSH versions start at 0.98. The number of hosts significantly decrease with a cosine similarity score of 0.90 and higher. Cowrie responses are not too far away to OpenSSH with an average of 0.80. However, scanning through the web with a minimum score of 0.90 and higher would exclude all honeypots. Thus, distinguishing Cowrie from OpenSSH with SSH packets is a feasible method. Moreover, Vetterl [74] performed an Internet-wide scan, and detected 758 Kippo and 2021 Cowrie honeypots. These results show that the values of honeypots would decrease to zero when large fingerprinting activities are used.

Vetterl [74] states that current low- and medium-interaction honeypots have a generic weakness due to the underlying off-the-shelf libraries. Cowrie is based on

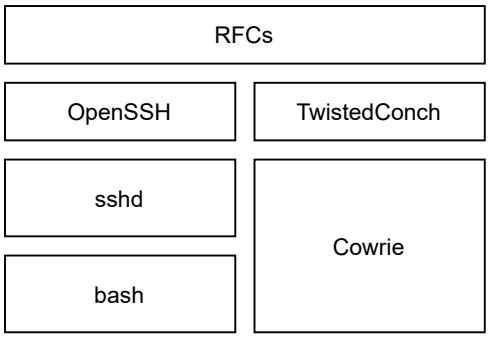


Figure 5.3: Architecture of OpenSSH and Cowrie. OpenSSH and TwistedConch have subtle differences (derived from [74])

TwistedConch[1], a Python 2/3 library that implements the SSH protocol. Any bash command and its response are tweaked by Cowrie, and thus, resulting in a discrepancy to OpenSSH. For example, Cowrie version 1.1.0 missed `tftp`[2] and came with version 1.2.0. Therefore, it is a continuous struggle of adding new commands to avoid early disclosures of Cowrie.

Figure 5.3 shows the difference between OpenSSH and Cowrie. Both have to fulfill the RFC 4250 [46] requirement on top. OpenSSH and TwistedConch implement the SSH protocol. As an example, Vetterl [74] found that Cowrie used to have random bytes for the `SSH2_MSG_KEXINIT` packet[3] unlike OpenSSH. With respect to RFC4253 [78] that defines the Binary Packet Protocol (BPP) of SSH, the random padding is used to solidify the total length of the packet to be a multiple of the cipher block size. The RFC in section 6 defines that the padding have to consist of 4 random bytes. Based on the statement of the OpenSSH authors, random bytes have been changed to `NULL` characters due to no security implications. Thus, an adversary could have detected a Cowrie honeypot with a single `SSH2_MSG_KEXINIT` packet. Nowadays, Cowrie adapted itself to have `NULL` characters as padding. However, these subtle differences influence the cosine similarity coefficient.

5.3 Experiment 1: Reproduce Vetterl et al.'s findings

First, the reproduction of the outdated OpenSSH library that Vetterl [74] used will be investigated. In his work he used OpenSSH 7.5$P1$ which deviates from the latest

[1] TwistedConch 12.0.0 on Github

[2] Is

[3] Each packet consists of the packet and padding length, the Message Authentication Code (MAC), a payload, and a random padding.

Table 5.1: Overview of the cosine similarity of OpenSSH, Cowrie, and Twisted

		A	B	C	D	E	F	G	H	I	J
OpenSSH 6.6	A	-	0.98	0.98	0.94	0.94	0.42	0.78	0.79	0.79	0.79
OpenSSH 6.7	B		-	0.98	0.98	0.98	0.41	0.80	0.81	0.81	0.80
OpenSSH 6.8	C			-	0.96	0.96	0.42	0.78	0.79	0.79	0.79
OpenSSH 7.2	D				-	0.98	0.42	0.80	0.80	0.80	0.80
OpenSSH 7.5	E					-	0.42	0.78	0.79	0.79	0.79
Twisted 15.2.1	F						-	0.50	0.51	0.51	0.52
Cowrie 96ca2ba	G							-	0.98	0.98	0.98
Cowrie dc45961	H								-	0.99	0.99
Cowrie dbe88ed	I									-	0.99
Cowrie fd801d1	J										-

version 8.8P1. Older versions rely on OpenSSL 1.0.2 which includes outdated algorithms and functions. For the `SSH2_MSG_KEXINIT` packet, the encryption algorithm blowfish-cbc has been removed with version 7.6P1, and thus, are outdated. Building the version 7.5P1 requires the libraries libssl (1.0.2), libssl-dev (1.0), libssh-dev (0.7.3-2), and libssh-4 (0.9.6-1). All of these libraries are outdated, and have been removed from any Debian installation. Using the latest versions of these libraries result in errors such as missing encryption algorithms and host key algorithms. Thus, replacing the libraries is a necessary task. It required to download the libraries, remove the current versions, and install the outdated ones. The version 7.5P1 allows to modify the proposal of the key exchange initialization message in a single file. On the contrary, this has been removed starting from version 7.6P1. After compiling the application, we test its behavior with a Debian 11 Buster and a Debian Jessie 9 Docker image. Both are new machines that have no other packages installed than the OpenSSH server. Debian 11 uses the latest OpenSSH version whereas Jessie is at 6.7P1. These environments help us to uniquely identify variations in the protocol version.

Listing 5.2 shows the connection attempt with our adjusted version string and `SSH2_MSG_KEXINIT` packet. Both Debian machines return the same response. Using the outdated OpenSSH version 7.5P1 results in an incompatibility. OpenSSH outlines that blowfish-cbc is not supported anymore. OpenSSH kept the encryption algorithm usable for compatibility reasons for clients until 7.6P1. Later, patches removed the blowfish-cbc from the SSH server, and thus, a reproduction of Vetterl [74] remains not feasible with state-of-the-art OpenSSH versions. However, testing it with version 7.3P1 that has been compiled on the machine results in a

Listing 5.2: OpenSSH connection attempt for version 7.5$P1$ and 8.8$P1$ with probed key exchange initialization message. All non-essential debug information have been removed to lay emphasis on the modified key exchange initialization.

```
1 OpenSSH_7.5p1, OpenSSL 1.0.2u  20 Dec 2019
2 Local version string SSH-2.2-OpenSSH
3 SSH2_MSG_KEXINIT sent
4 SSH2_MSG_KEXINIT received
5 kex: algorithm: ecdh-sha2-nistp256
6 kex: host key algorithm: ssh-dss
7 Unable to negotiate with ::1 port 22: no matching cipher
    ↪ found. Their offer: aes128-ctr,aes192-ctr,aes256-ctr
    ↪ ,aes128-gcm@openssh.com,aes256-gcm@openssh.com,
    ↪ chacha20-poly1305@openssh.com
```

Listing 5.3: Cowrie connection attempt with probed key exchange initialization message. All non-essential debug information have been removed to lay emphasis on the modified key exchange initialization.

```
1 OpenSSH_8.8p1, OpenSSL 1.1.1l  24 Aug 2021
2 Local version string SSH-2.2-OpenSSH
3 SSH2_MSG_KEXINIT sent
4 Bad packet length 1349676916.
5 ssh_dispatch_run_fatal: Connection to 129.206.5.74 port
    ↪ 22: message authentication code incorrect
```

successful connection attempt. Vetterl [74] does not outline any expected response of OpenSSH, thus, we have to assume that a connection attempt would have been successful due to the existing ciphers during that time. Adapting OpenSSH version 8.8$P1$ with chacha20-poly1305 instead of blowfish-cbc for the encryption algorithm results in a successful connection attempt. Thus, we have adapted the key exchange initialization to use chacha20-poly1305 as encryption algorithm instead. Next, the DSA host key algorithms are marked as too weak, and are not included automatically during the key exchange initialization. Using ssh-dss requires the extra flag `-oHostKeyAlgorithms=+ssh-dss`. In addition, we have tested it with the ssh-ed25519 host key algorithm, and the response has been promising to probe instances. So far, the adaptions of the `SSH2_MSG_KEXINIT` packet includes ecdh-sha2-nistp521 as key-exchange algorithm, ssh-ed25519 as host key algorithm, chacha20-poly1305 as encryption algorithm, hmac-sha1 as mac algorithm and zlib@openssh.com as compression algorithm has been successfully tested on our two Debian instances. Respectively, for OpenSSH version 8.8$P1$ we have updated the fingerprinting method by replacing the encryption and host key algorithm.

Most interesting question remains the response deviation of Cowrie. For instance, we use the default Cowrie implementation version $v.2.3.0$[4] of our T-Pot instance. Listing 5.3 outlines the connection attempt. Unambiguously, Cowrie results in a `bad packet length *` exception, and thus, deviates fundamentally from an OpenSSH response. The underlying off-the-shelf library TwistedConch checks if a packet is within 1048576 bytes (1 MB) (Listing 5.4). Any packet that exceeds that limit causes this exception that results in a connection loss of the client. When Cowrie tries to get the packet of a request this static check will be performed. It remains dubious why TwistedConch has added it whenever an SSH packet has to be returned. In the RFC 4253, the minimum packet size is 5 bytes whereas maximum packet size is set to 32768 bytes (256 KB). Debugging Cowrie shows that the exception occurs during the version string validation (Listing 5.5). The server validates if the version string matches the allowed versions 1.99 and 2.0. Any version higher or lower than that results in a `Protocol major versions differ.\n` exception by calling the function `_unsupportedVersionReceived`. This response would match the behavior of OpenSSH.

Vetterl [74] claims that TwistedConch results in a `bad version *` exception. This issue has been fixed in the meantime by Cowrie, and thus, do not leak vulnerable information anymore. We have tested Cowrie and OpenSSH with the version strings 1.0, 2.0 and 2.2. As a result, for Cowrie the `bad packet length *` exception only occurs when the version does not match the expected ones. This result diverges from OpenSSH. For OpenSSH only versions lower than 1.99 results in the same exception as Cowrie. For any higher version, the connection can be acquired successfully. We assume that Cowrie has a bug during the version string validation. Debugging Cowrie shows that the method to return the `Protocol major versions differ.\n` exception is called, however, our client does not retrieve this message. Respectively, we assume that the underlying library TwistedConch is responsible for the wrong return value.

As a conclusion, these are the protocol deviations that Vetterl [74] has presented in his work. Thus, we could successfully recreate his findings by detecting Cowrie on transport level. Adversaries who modify their SSH client to send our specific version string and key exchange initialization message could detect Cowrie honeypots and stop any further activity.

5.4 Attempt to Disguise Cowrie

Cowrie has to be tweaked to hide its generic weakness. Fixing the major flaws in Cowrie to avoid early detection remains an ephemeral patch. Continuing using libraries that re-implement the behavior of OpenSSH results in adversaries trying to

[4]Cowrie v2.3.0 on GitHub

Listing 5.4: TwistedConch packet length validation.

```
1 def getPacket(self):
2     ...
3     if packetLen > 1048576: # 1024 ** 2
4         self.sendDisconnect(DISCONNECT_PROTOCOL_ERROR,
5                             'bad packet length %s' %
                                ↪ packetLen)
6     return
7     ...
```

find subtle protocol differences and blacklist any related host machine that deviates. Such approaches could be achieved by any internet-large scanning and calculate the cosine similarity coefficient. Thus, the value of honeypots especially Cowrie would decrease to almost zero. Therefore, a new solution is required to disguise SSH honeypots. Vetterl [74] presented a solution to use OpenSSH as an intermediary instance between the attacker and Cowrie. Unfortunately, this solution is outdated, and newer versions include major changes to structure and functions. Thus, our concept is based on Vetterl [74] solution, however, due to newer available versions we have updated it to the latest OpenSSH version. OpenSSH itself is not capable by default to function as an intermediary, therefore, we have to adjust the latest OpenSSH version to enable this feature. Figure 5.4 visualizes the flow of SSH packets between an attacker and Cowrie. Cowrie is hidden in the background, and is only accessible through the loop back address `127.0.0.1:65522`. Our updated `sshd` daemon is exposed to the Internet, and is accessible through `129.206.5.157:22`. Any connection obtain to OpenSSH will be forwarded to our honeypot by a NAT rule (iptables -t nat -A PREROUTING -p tcp –dport 22 -j REDIRECT –to-port 65222). Respectively, an attacker should not be able to detect Cowrie by response deviations.

For instance, we use the latest OpenSSH version $8.8P1$[5]. Our implementation is based on Vetterl [74] version $6.3P1$[6]. As mentioned beforehand, due to major differences between both versions a smooth transition is unattainable without modifications. However, the basic idea to morph OpenSSH into an intermediary instance stays the same. In total, to change sshd daemon to work as an intermediary includes:

- A separate channel to communicate with the attacker and forward the packets to Cowrie.
- An authentication that permits any connection to Cowrie.

[5]OpenSSH 8.8P1 on GitHub
[6]sshd-honeypot on GitHub

Listing 5.5: Cowrie version string validation. It tweaks the same results as OpenSSH.

```
def _unsupportedVersionReceived(self, remoteVersion:
    ↪ bytes) -> None:
    """
    Change message to be like OpenSSH
    """
    self.transport.write(b"Protocol major versions differ
        ↪ .\n")
    self.transport.loseConnection()

def dataReceived(self, data: bytes) -> None
    ...
    if not self.gotVersion:
        ...
        self.otherVersionString = self.buf.split(b"\n")
            ↪ [0].strip()
        ...
        # Checks if the version string has a correct
            ↪ format
        m = re.match(br"SSH-(\d+.\d+)-(.*)", self.
            ↪ otherVersionString)
        if m is None:
            ...
            self.transport.write(b"Invalid SSH
                ↪ identification string.\n")
            self.transport.loseConnection()
            return
        else:
            ...
            # Checks if version string is either 1.99 or
                ↪ 2.0
            if remote_version not in self.
                ↪ supportedVersions:
                self._unsupportedVersionReceived(self.
                    ↪ otherVersionString)
                return
            ...
        ...
    ...
```

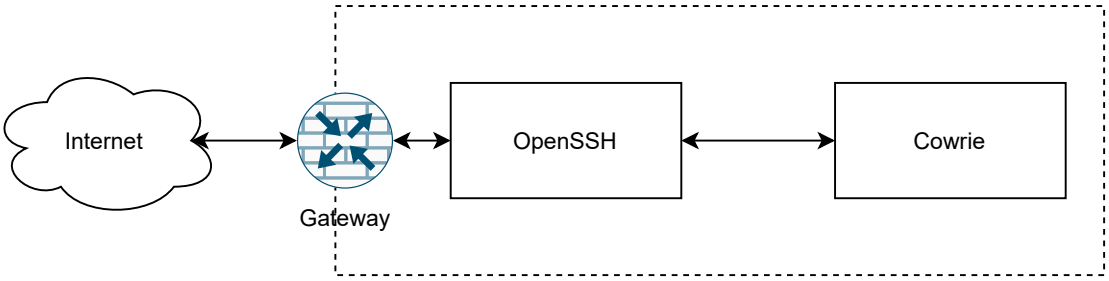


Figure 5.4: Architecture of OpenSSH and Cowrie. OpenSSH and TwistedConch have subtle differences (derived from [74])

- Tweaking the session to write packets in the new channel.

Respectively, a detailed description of the adaption will be presented. The easiest step is to tweak the authentication in the `auth-passwd.c` to permit any session so that an incoming connection can be forwarded to Cowrie. Originally, OpenSSH checks each session if the chosen authentication method returns true. Our server has to return true for any client in the `allowed_user` function to skip the authentication process. Cowrie continues the authentication process, and communicates with the attacker. In OpenSSH, communications are handled in channels as seen beforehand in section 5.1. Technically, the sshd daemon opens for each session a SOCKS connection to communicate with the client. SOCKS is a network protocol to exchange packets between a server and client. To communicate with Cowrie, the sshd daemon needs a separate channel to store the attacker's session, and forward packets. The channel is implemented in version $6.3P1$ and can be used in $8.8P1$ with minor adaptions. In the main method when sshd is starting, the channel is created and opens a connection to the running Cowrie instance so that a new session can forwarded. If Cowrie is not accessible, the startup would fail. Thus, Cowrie has to run prior to SSH. Next, the server loop that is responsible to connect the client to the correct port has to be modified in order to put direct TCP/IP connections in our honeypot channel. Without this adaption, no packet would be received by Cowrie. The function `server_request_direct_tcpip` handles these connections. For instance, it checks if the TCP forwarding port for Cowrie is defined, and connects the current session to the respective port only if a communication to Cowrie is feasible. Lastly, we have to adapt the sshd daemon to start and set up the channel. In addition, for an easy configuration of the daemon an extension of the configuration to set the Cowrie IP address and port has been included. After a compiling our version, a brief test proofed a valid connection to the sshd daemon.

Listing 5.6: Cowrie log information.

```
1 New connection: 127.0.0.1:65522 [session: 2ca9a619ceb8]
2 Remote SSH version: SSH-2.0-libssh_0.9.6
3 SSH client hassh fingerprint: ....
4 kex alg=b'curve25519-sha256' key alg=b'ssh-ed25519'
5 outgoing: b'aes256-ctr' b'hmac-sha2-512' b'none'
6 incoming: b'aes256-ctr' b'hmac-sha2-512' b'none'
7 connection lost
```

5.5 Experiment 2: Avoid fingerprinting of Cowrie

The last experiment to conclude this chapter is to test if our concept helps to disguise Cowrie and avoid fingerprinting based on a custom local string version and key exchange initialization message. For instance, we have used Vetterl [74] original 6.3P1 sshd honeypot, as well as the newly implemented version 8.8P1 with Cowrie version 2.3.0. Both versions have been tested in heiCLOUD and locally in an encapsulated environment. All requests do not result in a bad packet length, and thus, are behaving like an original sshd daemon. Only the older version 6.3P1 had problems to coup with new encryption and host key algorithm. Therefore, the concept is capable of forwarding any related packet to Cowrie, and hiding the generic weakness of TwistedConch. In Listing 5.6, Cowrie receives the connection and logs information respectively. Currently, one downside is the connection loss that happens due to timeout restrictions. This issue is a minor bug, and could be fixed in the future. As a conclusion, this experiment has shown that the initial idea of hiding Cowrie in the background and directing the message through OpenSSH prevents fingerprint activities of any adversary.

5.6 Discussion

Depending on the interaction-level, honeypots will always deviate from production instances. As we have seen in the two experiments beforehand, detecting a generic weakness is duable in a respective time, as well as mitigating it. Thus, finding and fixing weaknesses becomes a continuous cycle to improve honeypots. However, this chapter also outlined the importance of the libraries that are used. In this case, TwistedConch has been the bottleneck of Cowrie. On the contrary, the library has not been updated since 10 years, leaving space for future improvements. As a conclusion, such libraries should be chosen carefully to avoid any bugs and leave harmful information to attackers.

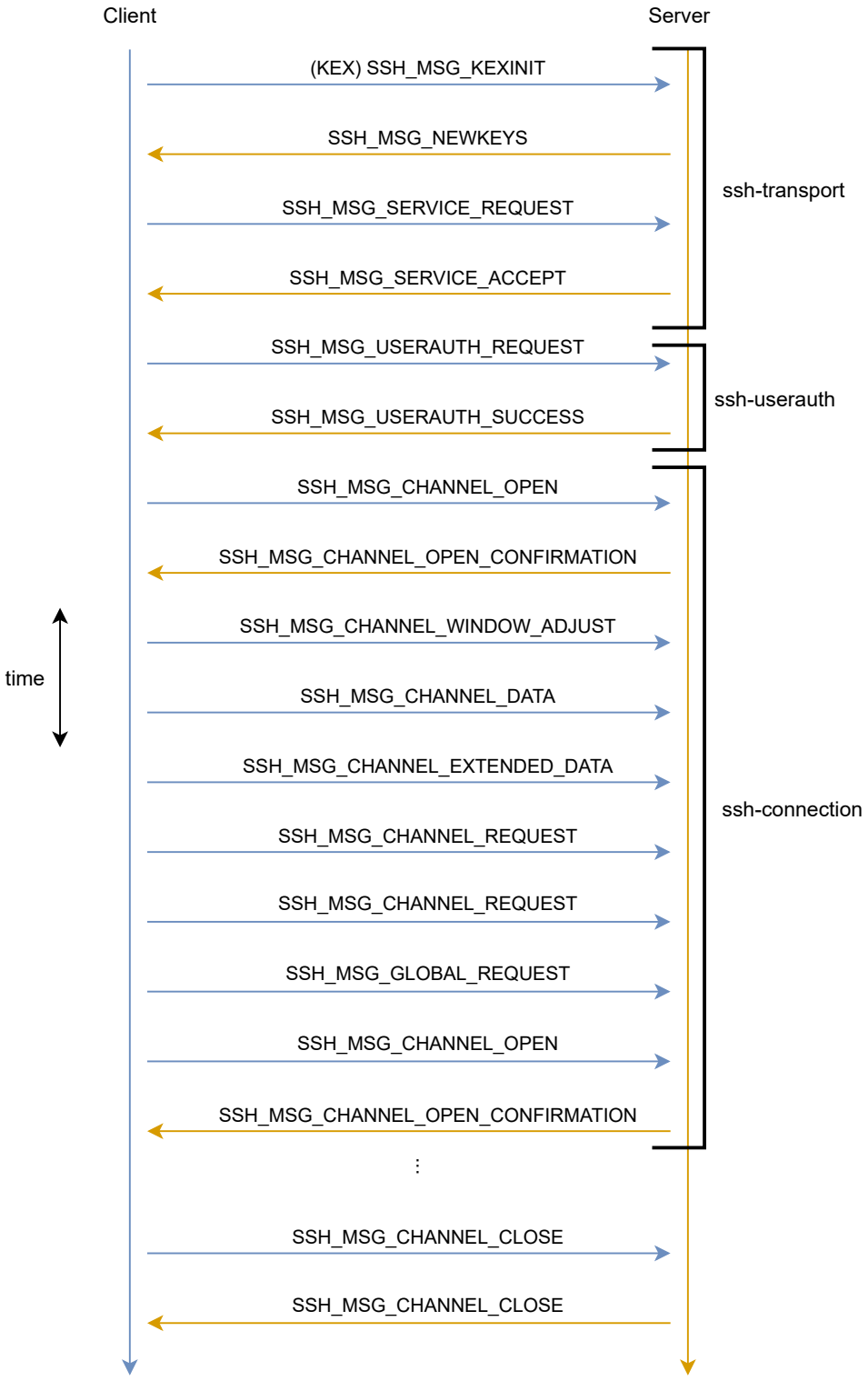


Figure 5.5: OpenSSH sample session flow diagram (derived from [72]). In addition, on the right side indicates the layers that are responsible for handling the messages.

Chapter 6

Conclusion

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Appendices

SSH Honeypot

auth-passwd.c

```
1  int
2  auth_password(struct ssh *ssh, const char *password)
3  {
4      Authctxt *authctxt = ssh->authctxt;
5
6      /* honeypot: Send the request to Cowrie */
7      int rc;
8      rc = authenticate_password(authctxt->user, password);
9      authctxt->valid = 1;
10
11     /* libssh returns different values compared to
          ↪ OpenSSH, so we need to adjust it
          ↪ SSH_AUTH_SUCCESS=0, for OpenSSH this returns 1
          ↪ */
12     logit("honeypot: Auth result sent from Cowrie: %d",
          ↪ rc);
13
14     if (rc == 0)
15     {
16         finish_connection_setup();
17         return 1;
18     }
19     else
20     {
21         return 0;
22     }
23         /* honeypot: end */
24     ...
25 }
```

auth.c

```
1  int
2  allowed_user(struct ssh *ssh, struct passwd * pw)
3  {
```

```
4       /* OpenSSH Support: - allow any user */
5       return 1;
6       /* OpenSSH Support: end */
7       ...
8   }
```

channels.c

```
1   static int
2   channel_handle_wfd(struct ssh *ssh, Channel *c,
3      fd_set *readset, fd_set *writeset)
4   {
5       ...
6       /* honeypot: Implement channel logic to forward data
          ↪ to Cowrie */
7       int nbytes;
8       char buffer[65507] = {0};
9       ssh_client_conns1[0].rfd = c->rfd;
10      ssh_client_conns1[0].wfd = c->wfd;
11      ssh_client_conns1[0].efd = c->efd;
12
13      // Make sure the connection to Cowrie is alive, if
          ↪ not, close the sshd-client connection as well
14      if (ssh_channel_is_open(channel_rw1.channel_data) &&
15              !ssh_channel_is_eof(channel_rw1.channel_data))
16      {
17          // Read data from the channel (Cowrie)
18          nbytes = ssh_channel_read_nonblocking(channel_rw1
              ↪ .channel_data, buffer, sizeof(buffer), 0);
19          if (nbytes > 0 && ssh_client_conns1[0].
              ↪ got_command != 1 && ssh_client_conns1[0].
              ↪ subsystem_req != 1)
20          {
21              write(ssh_client_conns1[0].wfd, buffer,
                  ↪ nbytes);
22              logit("honeypot: Write from Cowrie: %s, bytes
                  ↪ : %d", buffer, nbytes);
23          }
24          else if (nbytes > 0 && ssh_client_conns1[0].
              ↪ got_command == 1)
25          {
26              sshbuf_putf(&c->input, buffer, nbytes);
27              logit("honeypot: Write from Cowrie exec_cmd:
                  ↪ %s, bytes: %d", buffer, nbytes);
28          }
```

```
29
30      } else
31      {
32          if (ssh_client_conns1[0].counter_disconnect == 0)
33          {
34              logit("honeypot: Connection to Cowrie lost -
                    ↪ Close all");
35              ssh_client_conns1[0].to_disconnect = 1;
36          }
37      }
38      /* honeypot */
39      ...
40  }
```

misc.h

```
1  ...
2  //
     ↪ ================================================================
     ↪
3  // # sshd-honeypot: add code start
4  // Most of the variables we need are defined here */
5
6  // Redefining variables to avoid name collisions between
     ↪ libssh and openssh
7  typedef struct Session* Session_sshd_honey;
8  typedef struct Channel* Channel_sshd_honey;
9  typedef struct Authctxt* Authctxt_sshd_honey;
10 typedef struct ssh_channel_struct* ssh_channel_sshd_honey
     ↪ ;
11 typedef struct ssh_session_struct* ssh_session_sshd_honey
     ↪ ;
12
13 // Stores options for the MasterServer(MS),i.e. Cowrie,
     ↪ parsed by sshd_config
14 struct sshd_honey_options_defined
15 {
16      int port;
          ↪                                                    //
          ↪  Port
17      char ip[256];
          ↪                                                  //
          ↪ IPv4 address
```

```
18      char username[256];
          ↪                                          // Username
          ↪ in case specified
19      char server_version[256];
          ↪                                  // Server
          ↪ identification string
20      int tcpForwardingPort;
          ↪                                     // Port for
          ↪ port forwarding
21      char tcpForwardingHost[256];
          ↪                                // IPv4 address for
          ↪ port forwarding
22  };
23  struct sshd_honey_options_defined sshd_honey_options;
24
25
26  // Stores sshd-cowrie session and channel
27  struct channel_rw_defined
28  {
29      int type;
          ↪
          ↪ // Channel type: 1 = shell, 2 = direct-tcp
30      ssh_session_sshd_honey session_data;
          ↪                                  // SSH MS session
31      ssh_channel_sshd_honey channel_data;
          ↪                                  // SSH MS channel
32      ssh_channel_sshd_honey channel_data_1;
          ↪                                // SSH MS channel
33
34  };
35  struct channel_rw_defined channel_rw1;
      ↪                                  // Structure for the
      ↪  SSH MS connection
36
37
38
39  // Stores details of incoming connections
40  struct ssh_client_chan_session_defined
41  {
42      ssh_session_sshd_honey initial_session;
43      Session_sshd_honey session;              // SSH
          ↪ session
44      Channel_sshd_honey channel;              // SSH
          ↪ channel
```

```
45      char ip[17];                                    // IPv4
          ↪ address
46      char port[6];                                   // Port
          ↪ number
47      char ip_port[23];                               // Stores
          ↪ client IPv4 addresses and ports (SourceID)
48      char laddr_lport[23];                           // Stores
          ↪ local Ipv4 address
49      int authenticated;                              // Stores if
          ↪ the client is authenticated 0=no, 1=yes
50      int to_disconnect;                              // Indicates
          ↪ if the client is to be disconnected 0=no, 1=yes
51      int counter_disconnect;                         // Indicates
          ↪ how often we asked to disconnect
52      char command[65507];                            // Saves a
          ↪ command from exec request
53      int got_command;                                // Indicates
          ↪ an exec request has been received (1/0)
54      int rfd;                                        // Channel
          ↪ File descriptor to read
55      int wfd;                                        // Channel
          ↪ File descriptor to write
56      int efd;                                        // Channel
          ↪ File descriptor extended (escape sequences)
57      int s_rfd;                                      // Session
          ↪ file descriptor to read
58      int s_wfd;                                      // Session
          ↪ file descriptor to write
59      Authctxt_sshd_honey authctxt;                   //
          ↪ Authentication context of the session (must be
          ↪ set to 1 to proceed)
60      int s_pid;                                      // Pid of
          ↪ session
61      int sent_details;                               // Indicates
          ↪ an exec request has been received (1/0)
62      char client_version[256];                       // Stores the
          ↪  remote client version string
63      char target_ip[17];                             // IPv4
          ↪ address
64      char target_port[6];                            // Port
          ↪ number
65      char initial_comm[512];                         //Ipv4
          ↪ address, source port and remote version of
          ↪ clients
```

```
66      int error;                                      // Indicates
          ↪ that something went terribly wrong (e.g. no
          ↪ Connection to Cowrie)
67      int subsystem_req;                              // Indicates
          ↪ if a subsystem has been requested
68
69
70  };
71  struct ssh_client_chan_session_defined ssh_client_conns1
      ↪ [1];
72
73  // Functions for the SSH Connection to Cowrie
74  void start_honeypot();
75  void finish_connection_setup();
76  int authenticate_password();
77
78  // # sshd-honeypot: add code end
79  //
      ↪ ============================================================================
      ↪
80  ...
```

serverloop.c

```
1   static Channel *
2   server_request_direct_tcpip(struct ssh *ssh, int *reason,
      ↪  const char **errmsg)
3   {
4       Channel *c = NULL;
5       char *target = NULL, *originator = NULL;
6       u_int target_port = 0, originator_port = 0;
7       int r;
8
9       if ((r = sshpkt_get_cstring(ssh, &target, NULL)) != 0
          ↪  ||
10          (r = sshpkt_get_u32(ssh, &target_port)) != 0 ||
11          (r = sshpkt_get_cstring(ssh, &originator, NULL))
              ↪ != 0 ||
12          (r = sshpkt_get_u32(ssh, &originator_port)) != 0
              ↪ ||
13          (r = sshpkt_get_end(ssh)) != 0)
14          sshpkt_fatal(ssh, r, "%s: parse packet", __func__
              ↪ );
15      if (target_port > 0xFFFF) {
16          error_f("invalid target port");
```

```
17          *reason = SSH2_OPEN_ADMINISTRATIVELY_PROHIBITED;
18          goto out;
19      }
20      if (originator_port > 0xFFFF) {
21          error_f("invalid originator port");
22          *reason = SSH2_OPEN_ADMINISTRATIVELY_PROHIBITED;
23          goto out;
24      }
25
26      debug_f("originator %s port %u, target %s port %u",
27          originator, originator_port, target, target_port)
              ↪ ;
28
29      /* XXX fine grained permissions */
30      if ((options.allow_tcp_forwarding & FORWARD_LOCAL) !=
            ↪  0 &&
31          auth_opts->permit_port_forwarding_flag &&
32          !options.disable_forwarding) {
33
34          /* honeypot: Implement direct-TCP/IP forwarding
              ↪ */
35          if (sshd_honey_options.tcpForwardingPort != 0)
36          {
37              /* Redirect to the host specified in
                  ↪ sshd_config */
38              c = channel_connect_to_port(ssh,
                  ↪ sshd_honey_options.tcpForwardingHost,
                  ↪ sshd_honey_options.tcpForwardingPort,
39                                          "direct-tcpip", "
                                              ↪ direct-tcpip
                                              ↪ ", reason,
                                              ↪ errmsg);
40              debug("honeypot: redirect
                  ↪ server_request_direct_tcpip: originator
                  ↪ %s port %d, target %s port %d",
41                  originator, originator_port,
                        ↪ sshd_honey_options.
                        ↪ tcpForwardingHost,
42                  sshd_honey_options.tcpForwardingPort);
43          }
44          else
45          {
46              /* Redirect to any host (sshd default - be
                  ↪ aware) */
```

```
47              c = channel_connect_to_port(ssh, target,
                    ↪ target_port, "direct-tcpip", "direct-
                    ↪ tcpip", reason, errmsg);
48          }
49
50      } else {
51          logit("refused local port forward: "
52              "originator %s port %d, target %s port %d",
53              originator, originator_port, target,
                    ↪ target_port);
54          if (reason != NULL)
55              *reason =
                    ↪ SSH2_OPEN_ADMINISTRATIVELY_PROHIBITED;
56      }
57      /* Make sure cowrie is aware of all requests (
            ↪ successful or not) */
58      ssh_channel_open_forward(channel_rw1.channel_data_1,
59                               target, target_port,
60                               originator, originator_port)
                                    ↪ ;
61
62      sprintf(ssh_client_conns1[0].target_ip, "%s", target)
            ↪ ;
63      sprintf(ssh_client_conns1[0].target_port, "%d",
            ↪ target_port);
64      /* honeypot: end */
65
66  out:
67      free(originator);
68      free(target);
69      return c;
70  }
```

sshd.c

```
1  //
       ↪ ============================================================
       ↪
2  // # honeypot: add code start
3
4  #include "ssh_new/libssh.h"
5
6
7
8  int ssh_ms_is_running                = 0;
```

```
 9 int const size_buffer                  = 65507;
     ↪                  // Define buffer size (MAX UDP SIZE
     ↪ 65507)
10
11
12
13
14
15 void start_honeypot()
16 // Creates the SSH connection to Cowrie
17 // 1. Raw socket
18 // 2. SSH logic
19 {
20     // Initialisation for 1. Raw socket
21     int clientSocket;
22     struct sockaddr_in serverAddr;
23     socklen_t addr_size;
24
25     // Initialisation for 2. SSH logic
26     int rc;
27     int verbosity = SSH_LOG_WARNING;                //
         ↪ Define SSH verbosity
28     ssh_session session;                            //
         ↪ SSH session
29     session = ssh_new();                            //
         ↪ Create a new session
30
31
32     /* 1. Connect to Cowrie - raw socket*/
33     clientSocket = socket(PF_INET, SOCK_STREAM, 0);
34     serverAddr.sin_family = AF_INET;
35     serverAddr.sin_addr.s_addr = inet_addr(
         ↪ sshd_honey_options.ip);
36     serverAddr.sin_port = htons(sshd_honey_options.port);
37     addr_size = sizeof serverAddr;
38
39     if (connect(clientSocket, (struct sockaddr *) &
         ↪ serverAddr, addr_size) < 0)
40     {
41         ssh_client_conns1[0].error = 1;
42         logit("sshd_honey: Connection to Cowrie (raw
             ↪ socket) IPv4 %s:%d failed",
             ↪ sshd_honey_options.ip, sshd_honey_options.
             ↪ port);
```

```
43      }
44      else
45      {
46          /* Communicate the clients IPv4 address, port
               ↪ number and ssh client version via the raw
               ↪ socket to Cowrie */
47          sprintf(ssh_client_conns1[0].initial_comm, "%s%s"
               ↪ , ssh_client_conns1[0].ip_port,
               ↪ ssh_client_conns1[0].client_version);
48          if(send(clientSocket , ssh_client_conns1[0].
               ↪ initial_comm, strlen(ssh_client_conns1[0].
               ↪ initial_comm) , 0) < 0)
49          {
50              ssh_client_conns1[0].error = 1;
51              logit("sshd-honeypot: Communication with
                   ↪ Cowrie (raw socket) IPv4 %s:%d failed",
                   ↪ sshd_honey_options.ip,
                   ↪ sshd_honey_options.port);
52          }
53          else
54          {    /* 2. Setup the SSH logic*/
55              ssh_options_set(session, SSH_OPTIONS_FD, &
                   ↪ clientSocket);
56              ssh_options_set(session, SSH_OPTIONS_HOST,
                   ↪ sshd_honey_options.ip);                //
                   ↪ SSH Master Server IP
57              ssh_options_set(session, SSH_OPTIONS_PORT, &
                   ↪ sshd_honey_options.port);             //
                   ↪ SSH Master Server Port
58              ssh_options_set(session,
                   ↪ SSH_OPTIONS_LOG_VERBOSITY, &verbosity);
                   ↪                 // SSH Verbosity Level
59              rc = ssh_connect(session);
                   ↪                        // Create a SSH
                   ↪ connection with the specified session
                   ↪ options
60              if (rc != SSH_OK)
61              {
62                  ssh_client_conns1[0].error = 1;
63                  logit("sshd-honeypot: Connection to
                       ↪ Cowrie (SSH) IPv4 %s:%d failed",
                       ↪ sshd_honey_options.ip,
                       ↪ sshd_honey_options.port);
64              }
```

```
65              else
66              {
67                  ssh_client_conns1[0].initial_session =
                      ↪ session;  // Save session for later
                      ↪ use
68                  ssh_client_conns1[0].got_command = 0;
                      ↪             // Set defaults
69                  ssh_client_conns1[0].sent_details = 0;
70                  ssh_client_conns1[0].subsystem_req = 0;
71                  ssh_client_conns1[0].counter_disconnect =
                      ↪  0;
72              }
73          }
74      }
75  }
76
77
78
79  int rc;
80  int authenticate_password(const char *username, const
      ↪ char *password)
81  {
82      fatal("sshd-honeypot: Auth with username: %s,
          ↪ password: %s", username, password);
83      /* We do not allow logins if we could not connect to
          ↪ Cowrie */
84      if (ssh_client_conns1[0].error != 1)
85      {
86          rc = ssh_userauth_password(ssh_client_conns1[0].
              ↪ initial_session, username, password);
87      }
88      else
89      {
90          rc = -1;
91      }
92      return rc;
93  }
94
95
96  void finish_connection_setup()
97  {
98      // Create a channel pair
99      ssh_channel channel;
100     ssh_channel channel_1;
```

```
101     channel = ssh_channel_new(ssh_client_conns1[0].
          ↪ initial_session);
102     channel_rw1.channel_data = channel;
103     channel_1 = ssh_channel_new(ssh_client_conns1[0].
          ↪ initial_session);
104     channel_rw1.channel_data_1 = channel_1;
105     ssh_channel_open_session(channel_rw1.channel_data);
          ↪   // Open/request a channel
106     channel_rw1.type = 1;
          ↪                                   // Set type to
          ↪ 1, i.e. shell
107     channel_rw1.session_data = ssh_client_conns1[0].
          ↪ initial_session; // Save session
108     logit("sshd-honeypot: Connected to Cowrie IPv4 %s:%d"
          ↪ , sshd_honey_options.ip, sshd_honey_options.port
          ↪ );
109
110 }
111
112
113 // # honeypot: add code end
114 //
      ↪ ================================================================
      ↪
115
116 /*
117  * Main program for the daemon.
118  */
119 int
120 main(int ac, char **av)
121 {
122     ...
123     // sshd_honey: edit
124     start_honeypot();
125     ...
126     // sshd_honey: edit, reset server configurations
127     // Set banner if not defined in sshd config
128     if (strlen(sshd_honey_options.server_version) <= 0)
129     {
130         sprintf(sshd_honey_options.server_version, "%s",
              ↪ SSH_VERSION);
131     }
132     logit("sshd_honey: Deamon started with %s as server
          ↪ version", sshd_honey_options.server_version);
```

```
133     ...
134     //sshd_honey: edit
135     // Somewhere here get the socket and save ip address
          ↪ and port
136     // Get IPv4 address and port number of the SSH
          ↪ connection
137     sprintf(ssh_client_conns1[0].ip_port, "%s;%d;",
          ↪ ssh_remote_ipaddr(ssh), ssh_remote_port(ssh));
138     sprintf(ssh_client_conns1[0].ip, "%s",
          ↪ ssh_remote_ipaddr(ssh));
139     sprintf(ssh_client_conns1[0].port, "%d",
          ↪ ssh_remote_port(ssh));
140     free(laddr);
141     // sshd_honey: edit --- end
142     ...
143 }
```