INTERCEPT+: SDN Support for Live Migration-based Honeypots

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Abstract—This paper introduces a novel honeypot for web application. Recently, web applications have been the target of numerous cyber attacks. In order to catch up with new vulnerabilities in the applications, using a honeypot system is a feasible solution. However, there remains difficulty for developing a lure-able, protect-able, and deception-able honeypot for web applications.

In this paper, we present an approach in which attackers will be automatically isolated from the real web server to the honey web server. The key features are employing migration techniques to create a virtual machine as a honey web server, making the honeypot to equip the same memory and storage devices of the real systems, and controlling network traffic with OpenFlow in order to isolate honeypots from the real server. This paper also shows our design and implementation of INTERCEPT+, a component of honeypot systems for web applications.

Keywords—Honeypot, Web application, Live Migration, OpenFlow

I. INTRODUCTION

Web applications have become one of the popular targets for cyber attacks. This is due to several reasons; for one, the web applications manage a wide array of information including financial data, medical records, social security, therefore attacks aim at stealing the information [1]. Another reason provided by McAfee [2] is the ease of exploitation of web vulnerabilities, combined with the proliferation of low-grade software applications written by inexperienced developers. According to the report from OWASP [3], web vulnerabilities allow a remote attacker to execute injection attacks, e.g., SQL injection [4] and/or Cross Site Scripting [5] attacks that input malicious codes to pose web hijacking, information leakage, malware infection, and so on.

A web application firewall (WAF) is one of the solutions against attacks which filters suspicious code injection. Generally, it inspects the application layer so it usually comes as an appliance type or as a server module [6]. There are several algorithms for distinguishing suspicious codes from HTTP request. The one is rule-based filtering, which checks the HTTP request with the database of known attack patterns. Besides the protection via blacklisting, WAF usually supports whitelisting; with active whitelisting, the rule set of the WAF describes the exact behavior of the application [7]. Different from the rule-based methods, heuristics-based methods calculate the likelihood of being a malicious code and compare the likelihood with the defined discrimination threshold.

Unfortunately, it still remains challenges while preventing code injection attacks. The rapid development of web applications arises numerous program bugs, the cause of web vulnerabilities. Building a perfect blacklist is therefore tedious work. In the case of the whitelisting, the issue is that it requires WAF operators to maintain rules of the legitimate input and output for the applications. The core issue in heuristics-based methods is detection accuracy. To achieve higher detection accuracy, monitoring injection attacks and analysis of them are necessary.

Herein, we present a server-type, honeypot systems for observing web attacks. Theoretically, honeypots are decoy systems to gather information regarding an attacker, and have deception and luring capabilities. A honeypot offers some services that appear perfectly normal to the attackers, and looks alike as if the system has honey, e.g., valuable data. Our motivation is to collect the information related to cyber attacks toward web applications using the honeypot.

Our developed INTERCEPT+ is a component of honeypot for web applications, and it upgrades our previous work named INTERCEPT [8] which was designed for tailoring a honey web server by creating a perfect copy of the legitimate server with live migration techniques. INTERCEPT+ enables to isolate attackers’ traffic with the OpenFlow-based system to the honeypot system created by live migration. Since our honeypot has the perfect copy of the real server, the pair of media access control (MAC) address and IP address is the same as that of the real server. In order to avoid MAC and/or IP address conflicts, INTERCEPT+ induces the attack packets to the honeypot regardless of the addresses.

We show that our developed OpenFlow-based packet forwarder can correctly control the packets from normal users and attackers. We also show that Live-Migration technique used in
INTERCEPT+ can make its perfect copy in short time and it makes almost no data corruption.

The rest of paper is organized as follows. Section II briefly explain related work, and section III designs the architecture of the honeypot for web applications. Section IV and V implement INTERCEPT+, our proposed honeypot aspects from the migration-based honeypot and OpenFlow-based packet forwarder, in respectively. Section VI shows the preliminary evaluation of INTERCEPT+ and section VII discusses the missing piece toward the suitable honeypot. We finally summarize our contribution in section VIII.

II. RELATED WORK

Honeypot systems can be categorized into four types, namely (i) high-interaction client-type honeypot, (ii) low-interaction client-type honeypot, (iii) high-interaction server-type honeypot, and (iv) low-interaction server-type honeypot. The type, server or client, means that the honeypot systems work as server or client computer. The key characteristics of the interaction was explained in many articles [9]–[11], and the summary is shown in Table I.

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Actual OS / applications</th>
<th>Risk</th>
<th>Operational cost</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>no</td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>high</td>
<td>yes</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

The client-type honeypot systems are used to discover new vulnerabilities in the client side systems, such as client OSes, web browsers and their plugins. The honeypot systems usually crawl malicious web content, allow malicious content to exploit the system, and observe the attack methodologies. For examples of the type (i), HoneyClient [12], Capture-HPC [13], and Marionette [14] are used to analyze malicious URLs for blacklisting. If a system, which was composed of the latest version of Windows, Internet Explorer and plugins, was compromised while browsing, it can be assumed that there was new vulnerability in the system and the honeypot succeeded to find it. Instead of using the actual systems, the type (ii) honeypot systems such as Honey-C [15] and Monkey-Spider [16] mimic the client OSes, IP stacks and applications. While the attacks target particular applications, it can reduce the risk for compromising. However, the observable information during the attacks tends to be limited in comparison to the high-interaction honeypot, as shown in Table I.

The server-type honeypot systems aim at obtaining new vulnerabilities by monitoring the trials of attack, penetration, and intrusion. In order to collect these events, the honeypot systems need to induce the malicious people to be targeted of the attacks. Since the type (iii) honeypot systems are faced to the risk for compromising, the abilities including containment are necessary. Referring to [17], we will explain the requirements of the honeypot systems. In the case of type (iv), the honeypot systems run tools aiming at emulated vulnerable systems. For example, Nepenthes [18] and Deception Toolkit [19] mimic the vulnerable applications. Unfortunately, there are several tools [20], [21] for identifying the systems remotely, therefore, the attacker are easily aware that their targeted system is honeypot.

III. DESIGN OF HONEYPOT FOR WEB APPLICATION

Our grand goal is to develop a novel honeypot system for web applications. In order to discover new vulnerability of web applications, honeypot systems facilitate to collect new attack methodology.

A. Requirements

Along with our survey described in section II, we define the following abilities that honeypot systems for web application should equip.

- **Luring ability**
  Due to the nature of honeypot, the system must be attractive for attackers.

- **Protection ability**
  The system must equip protection capability against the attacks. Containment must be work for preventing the abuse of the systems.

- **Deception ability**
  The system must have deception capability, in other words, attackers cannot distinguish that their targeted system is honeypot.

In the context of the honeypot systems for web applications, we decide to employ high-interaction server-type honeypot systems. Since web attacks often require to login to web applications before their execution, the low-interaction honeypots are required to emulate many web applications. It might be tedious, because this task is equal to make the clone of the targeted application.

B. Components

Our concept of the honeypot system is shown in Figure 1. In order to meet the luring requirements, it employs the actual web applications. A router normally sends to all web requests to the real web server. However, when suspicious web requests are detected, the router sends to the requests to the honey web server. This can meet the protection requirements hence the attacks must not be harm to the real web server.

The one of the difficult point is that a honey web server must have the same state to a real server. In other words, the honey server is required to have the same memory of the real server regarding to the login state, as well as files of web content including applications. We consider such case that the attacker’s login process is not different to the normal one, this procedure might be done in the real server. After completing the login procedure, the attacker sends suspicious requests to the web application, and the requests are forwarded to the honey web server by the router. To deal with such requests for the honey web server, the server must know the attacker’s login state as same as the real server. Otherwise, the honey server may return some error messages to the attacker; the attacker can have a chance to be aware of that they are quarantined to the honey systems. It cannot meet the deception requirement.
In order to meet the deception requirement, we decided to experiment with migration techniques. They enable a virtual machine to be physically moved from one physical machine to another in a transparent way [22]. It also enables to create the complete memory and storage copy of the real web server.

Another one of the difficult points is address duplication. Since the migrated virtual machine has the same MAC and IP address of the real server, it must be considered for the way of forwarding suspicious web requests to our proposed honeypot. Generally, a network router (L3 router) decides next hop for each packet regarding to the destination IP address, and a network switch (L2 switch) finally decides the destination with the MAC address. Therefore, the conflicts of IP and/or MAC address causes that the suspicious web requests are not delivered to the honeypot.

Instead of the traditional network routers/switches, we decide to employ a Software-Defined Network (SDN) architecture which enables flexible traffic management. Within the architecture, packet forwarding decisions are controlled by the OpenFlow protocol; an OpenFlow Switch (OFS) asks OpenFlow Controller (OFC) to deal with any packets when the OFS attempts to forward the packets. An OFC is an application that manages flow control and dictates how the OFS handles matching packets. As shown in Figure 1, the network switches behind the host OSES of both the real and honey web servers should be capable to the OpenFlow protocol and work as an OFS. For benign requests, the OFS sends them to the real web server. Oppositely, the OFS forwards a request to the honey web server whenever the request seems to be suspicious.

There still remains such problems that determination of suspicious requests, prevention of data leakage, avoidance of data corruption, and migration in short time period. For identifying suspicious requests, the likelihood of being an attack, which can be calculated by the heuristics-based WAF, is useful. This is just a case, but if there is slight possibility of the attack, the router in Figure 1 can forward packets to the honey web server. Even if the normal transaction is forwarded to the honey server, it must not be lost because the honey server can observe the transaction. Due to the honey server has the same state of the real server, it must not penalize normal users’ convenience.

In order to prevent data leakage, it can be considered to separate databases for real and honey web servers. The real database has entire tables and records, and the honey database has limited tables and records that are related to the user who logged in to the web applications. While the honey database should not contain the records to other users, the risk of data leakage might be thwarted.

The missing pieces are avoidance of data corruption and migration in short time period. This paper also discusses on development of the system in corresponding to these two problems.

### IV. IMPLEMENTATION OF LIVE MIGRATION-BASED HONEYPOT

In our study, we setup Ubuntu 13.04, Kernel-based Virtual Machine modules to two physical machines; their specifications are shown in Table II. We have modified QEMU [23] source codes. Due to the nature of migration techniques, a migration-source VM will power off to prevent a possible data corruption. Whenever our implement continues to run a source VM after migration, both suppression of the state change in the VM and prevention of the data corruption are necessary.

<table>
<thead>
<tr>
<th></th>
<th>Sender PC</th>
<th>Receiver PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Intel(R) i7-3610QM 2.30 GHz</td>
<td>Intel(R) i5-2430M 2.50 GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>8 GB</td>
<td>4 GB</td>
</tr>
<tr>
<td>Disk</td>
<td>1 TB ATA</td>
<td>500 GB ATA</td>
</tr>
<tr>
<td>NIC</td>
<td>RealTek RTL-8169 (Gigabit Ethernet)</td>
<td>RealTek RTL-8169 (Gigabit Ethernet)</td>
</tr>
</tbody>
</table>

In order to keep source VM running after migration, we modified the state of source VM will be changed when vm_stop_force_state() and runstate_set() are called via migration.c. It works fine, so the rest of problem is the data corruption.

At first, we used Full Live Block Migration (FLBM) for preventing data corruption. FLBM supports the entire disk copying, therefore, the source VM and destination VM have respectively their own virtual disk images. It enables that the source and destination VM have the same content in entire memory and block devices as well as avoiding data corruption. However, FLBM requires a lot of time due to the copying full disk images during migration procedure. It might not be good solution for honeypot, because an attacker would feel something is not normal.

Different from FLBM, it was feasible to use of Incremental Live Block Migration (ILBM). In the “incremental” mode,
only the blocks that were modified are migrated. QEMU’s disk image utility supports to create a snapshot image file. Instead of FLBM, ILBM can dramatically reduce the time during live migration, but it still needs couple of time; it can be assumed that these times are required for verifying disk consistency and for memory migration.

In order to reduce the time for verifying disk consistency, we tested LiveBackup [24] and DriveBackup [25]; the former enables the destination VM periodically polls the source VMs to the data which might be backup, and the latter enables to push the data from the source VM to the destination VM. However, these tools are designed for backup, due to that they only work when the source VM is surely powered off. If the source VM kept running, we confirmed that the data corruption or critical system failure occurred.

Instead of using backup tools, we observed that combination of NFS and advanced multi layered unification file system(AUFS) [26] worked fine. AUFS is a implementation of Union File Systems, which provides the function, called branch, to unite several directories into a single virtual file system. Based on the solution, we conducted our experiment as follows.

1) Setup snapshot image files
In order to reduce the further copy-on-write process, we decided to use snapshot. Besides to this, the source physical machine (PM) and the destination PM have the same base image file for the snapshot image file, and use the base image file to the same directory path in the physical machine. For example, if the destination PM puts the base image file into /root directory, the source PM also puts the base image file into /root.

2) Sharing snapshot
The source PM creates the snapshot and place the file into NFS server. The destination PM mounts the the NFS server as a read only file systems, and configure AUFS directory. For example, a NFS server exports /nfs directory and the destination PM mounts the place as a read-only file system, e.g., /ronfs. The PM then mounts /nfs as an AUFS system, in which /ronfs is a read only directory and any other directory, e.g., /tmp is a writable directory.

Instead of ILBM, this methodology employs copy-on-write to keep consistency of the VM disk image files between the source and destination VMs. We observed that the copy-on-write process will be started after the memory migration finished.

Finally, we employ Kemari [27] for reducing the time for memory migration. Kemari provides the feature of the fault tolerance for KVM, and makes the memory migration to be done in the background. The feature also enables the reduction of the time for migrating memory in INTERCEPT+.

Therefore, our prototype implementation is developed by modifying the latest version of Kemari. The figure 2 demonstrates how INTERCEPT+ works for the sender and the receiver VMs. The sender (physical machine) runs the VM as shown in Figure 2a and the receiver also runs the VM as shown in Figure 2b with enabling Kemari’s fault tolerant feature. The sender also starts the fault tolerant migration via sender’s QEMU monitor console with specifying the IP address of the receiver. In the case of Kemari, the sender VM still runs after finishing migration; the receiver VM does not start, but is suspended. After the receiver VM starts, the sender disables the fault tolerant feature and stops the sender VM by calling vm_stop(0) from migrate_ft_trans_error() function in migration.c. As we mentioned above, we comment out the vm_stop() function not to power-off the VM. In addition, we also modify the receiver for remotely starting the VM. Instead of inputting command in the receiver's console, INTERCEPT+ accepts the signal for launching the VM, as shown in Figure 2b.

### Algorithm 1 Pseudo Code of the OpenFlow-based Packet Forwarder

```plaintext
for all packets do
    Read the list of suspicious IP addresses
    if incoming packets from Internet then
        if the source IP address is listed then
            Send signals to finish live migration
            Forward the packet to the honey web server
        else
            Forward the packet to the real web server
        end if
    else if outgoing packets from the real web server then
        if the destination IP address is listed then
            Discard the packet
        else
            Forward the packet to the Internet
        end if
    else if outgoing packets from the honey web server then
        if the destination IP address is listed then
            Forward the packet to the Internet
        else
            Discard the packet
        end if
    end if
end for
```

V. IMPLEMENTATION OF THE OPENFLOW-BASED PACKET FORWARDER

This section demonstrates our implementation of OpenFlow-based packet forwarder. We installed the functions of OFC and OFS to one PC, its specification is shown in Table III. We chose RYU [28], a python framework for OFC, to develop our implementation as an OpenFlow application. We also selected Open vSwitch [29] for OFS. The OpenFlow PC has three network interface cards. One is used for the external connection, one is for connecting to the real web server and the other is for the honeyweb server.

The pseudo code of our implementation is shown in

<table>
<thead>
<tr>
<th>TABLE III: Specification of Physical Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenFlow PC</td>
</tr>
<tr>
<td>CPU: Intel Core i7-3632QM</td>
</tr>
<tr>
<td>Memory: 8 GB</td>
</tr>
<tr>
<td>Disk: 500 GBATA</td>
</tr>
<tr>
<td>NIC: RealTek RTL8111E3/8168/8411</td>
</tr>
</tbody>
</table>

(Gigabit Ethernet)
Algorithm 1. As we described in section III, it usually forwards all packets from the Internet to the real web server. Besides, all packets from the real server are also forwarded to the Internet. To implement these functions, the forwarder checks the list of suspicious IP addresses for each packet. If the source IP address of the packet was listed, the packet would be forwarded to the honey web server. Oppositely, the implementation continues to work as usual.

We considered such case that the suspicious packets could be detected. The OpenFlow-based packet forwarder immediately ran OS commands for sending signals on the host OS of the honey web server, in order to prepare the honey web server. It then forwarded all packets with suspicious source IP address from the Internet to the honey web server, after live migration was finished. This implementation was also designed to isolate the real server from the attacker. It discarded all packets with the suspicious destination IP address from the real web server to the Internet. In the case of outgoing packets from the honey web server, the forwarder did oppositely.

In addition to that, the forwarder also needed to retrieve the list of the suspicious IP addresses. Our implementation simply read a file for retrieving the address list.

VI. Evaluation

This section provides our evaluation results. Section VI-A shows the performance of the migration-based honeypot, and section VI-B analyzes the latency of the OpenFlow-based packet forwarder.

A. Live Migration-based honeypot

The requirements of the INTERCEPT+ were avoidance of data corruption and migration in short time period. The section show the detail conditions of the preliminary evaluation in which we used two physical machines as shown in Table II.

This evaluation employed three strategies for launching a honey server, namely Incremental Live Block Migration (ILBM), Live Memory Migration (LMM) with using AUFS for copying block devices, and INTERCEPT+, our modified version of Kemari with AUFS. We also prepared four types of snapshot images, whose size were 20, 50, 100, and 500 MegaBytes (MB) in respectively. Note that 20 MB is the minimum size for the snapshot image file in our experiment.

Based on the above conditions, we measured the time for launching virtual machines. For the cases of LMM with AUFS and INTERCEPT+, we compared the timestamp of the snapshot images created by copy-on-write with the time which started the migration. As for the case of ILBM, we manually measured the turn around time by calculating from the started time and the completed time. The results are summarized in Figure 3a, 3b, 3c, and 3d, where x axis denotes three cases, and y axis denotes the turn around time while creating honeypot. Note that our x axis range for each box graph is limited to the 20 seconds, for readability.

When the disk size was 20 MB, we observed that the minimum average of the turn around time was 2.00 seconds in the case of INTERCEPT+, followed by LMM with AUFS (11.72) and finally ILBM (14.90). In order to compare the responses in a less biased way, we performed Analysis of Variance (ANOVA) and Welch’s t-test ($p < 0.05$) for INTERCEPT+ and ILBM, and the result showed that there was statistical difference between the two turn around times in between INTERCEPT+ and ILBM ($p = 1.40E-32 (< 0.05), \nu = 18$). In addition to the INTERCEPT+ and LMM with AUFS, there also found statistical difference ($p = 7.62E-33 (< 0.05), \nu = 18$).

Even if the disk size was 500 MB, the minimum average of the turn around time was 43.23 seconds in the case of INTERCEPT+, followed by LMM with AUFS (53.22) and finally ILBM (56.51). According to our ANOVA results, we performed Student’s t-test ($p < 0.05$) for INTERCEPT+ and ILBM and found the statistical difference ($p = 3.78E-16 (< 0.05), \nu = 11.86$). There was also statistical difference between INTERCEPT+ and LLM with AUFS ($p = 4.00E-23 (< 0.05), \nu = 18$).

We also verified whether or not the data corruption occurred, and observed that there was no data corruption in all cases. Aspect from these observations, INTERCEPT+ succeeded to meet our requirements, avoidance of data corruption and migration in short time period. However, we also found that the turn around time increases if the snapshot file size became bigger. We will discuss this problem in section VII-B.

B. OpenFlow-based packet forwarder

In this section we performed the results of our preliminary evaluation. We analyzed the latency of the OpenFlow-based forwarder system.

At first we observed the packets under the normal situation in which no attackers exist. Secondly, assuming the IP 10.0.0.2 is detected as an attacker, we observed the packets. The VM migration takes place just when the first packet from 10.0.0.2 arrived. Then the signal is sent to the honeypot and packets from the attacker is sent to the honeypot server. In the last experiment, an attacker is detected and forwarded to the honey

![Fig. 2: Demonstration of INTERCEPT+ system](image-url)
web server during the TCP session. In every situation, we dumped packets at the client’s side. This is because we needed to know whether this honeypot system has ability to hide themselves from attackers, who is at client’s side. Of course, we verified that normal users can access to the real web server simultaneously even when the attacker exists and is directed to the honeypot.

The packet dumps taken by Wireshark [30] are shown in Table IV. Table IVa shows the packets from a normal user. In Table IVb the first TCP SYN packet from an attacker triggers the signal to finish live-migration and packets from the attacker is forwarded to the honeypot. In Table IVc, live migration took place during the TCP session. In the Table, the first row from the left shows the time the packets were observed. The second and third rows are the source and destination IP address respectively. The fourth is protocol. This information depends on the expression of Wireshark. The packets for the TCP three way handshake and other packets with ACK flag are TCP, and other packets related to HTTP protocol are shown as HTTP. The last row is the packet information. It shows the SYN, ACK flags about the TCP, while HTTP methods about the HTTP packets.

By comparing the difference between packets from a normal user and an attacker in Table IVa and IVb, we can see a slight delay. The control during TCP session caused one retransmission packet.

As a result, this packet forwarder system can correctly control the attack traffic to the honeypot web server and show almost no strange behaviors. Even though the control during the TCP session causes a retransmission packet, it is still difficult for attackers to detect this honeypot.
TABLE IV: Packets dumps at client’s side

A. Collection of attacks

Our motivation is to collect the information related to cyber attacks toward web applications using the honeypot. This section explains about the content of the information.

As shown in Figure 1, our concept contains detecting a suspicious request, creating a honey web server, preparing honey database, forwarding the request to the created server, and observing the behavior. Imagine if the request can be detected attacks without doubt. When the attack was well known and contained particular phrases that cause injection attacks, the rule-based detection can identify that the request is determinately attack. In this case, the information of the attack is not so new.

Aside from the well known attacks, we want to analyze suspicious attacks with honeypot. As we mentioned in section I, heuristics-based methods calculate the likelihood of being a malicious code and compare the likelihood with the defined discrimination threshold. Assuming if the calculated score 0 means benign and 1 means attacks, and more 0.5 is the threshold. For example, given calculated score 0.9 (> 0.5), it would be detected as attack rather than benign. However, even if the calculated score is 0.1, it might contain some suspiciousness. By observing the activity during the request, we considered that there is a potential chance for collecting new cyber threats.

Due to the fear of false positive, which is to label benign request as attack, a suspicious request might not be blocked. Instead, our approach seamlessly quantifies the suspicious request to the honey web server. Even if the false positive occurred, the service for the benign user of the web application would be continued without losing any convenience when following two conditions are met: (i) the honey web server has the same memory and disk information of the real server, and (ii) the honey database equips the information that used by this benign user. If the honey database has limited tables and records that are related to the user who logged in to the web applications, as we explained in section III, INTERCEPT+ might not penalize users’ convenience even if the false positive error occurred.

B. Deception ability

This section explains about deception ability. We developed INTERCEPT+ to create a perfect copy of environment for web applications based on virtualization techniques. To the best of our knowledge, it would be difficult that honey web server has the same memory of the real web server, including TCP session state and web application session information, without using VM.

The remain issue is time for creating the copy of VMs. If it requires a lot of times, remote attackers will be aware of unusual or strange behavior of the web servers.

Our INTERCEPT+ was designed to reduce the time for migration; use of Kemari and its fault tolerant feature to reduce the time for memory migration, and use of AUFS and its copy-on-write feature for live block migration. The rest of time is the time for copy-on-write in AUFS. The creation time increases when the size of the snapshot disk image file becomes larger. The periodic “re-basing”, the procedure of merging the base and the snapshot, might be necessary to keep the size of the snapshot to be reasonable.

The other solution is that use of rapid migration techniques. INTERCEPT+ needs to replicate the VM instance rather than migration, so we need to carefully choose the suitable techniques to avoid data corruption. As well as as Kemari’s fault tolerant functions, which do memory migration in the background manner, the fault tolerant functions for block disk image might be feasible. Actually, cloud storage techniques such as GlusterFS [31] and/or Sheepdog [32] have the fault tolerant features and replicate the disk images in the storage network. By modifying their replication functions, there is possibility for creating the perfect copy of VMs in very short time period even if the disk size is large.

Toward development of honeypot for web applications, INTERCEPT+ needs to interconnect to other modules, namely
determination modules for suspicious requests. On the inte-
gregation of INTERCEPT+ and the remaining module, it needs
to define the temporal requirements. The required time for
detection, direction and preparation of honeypot might be
calculated along with each requirement, but it is beyond the
scope of this paper.

C. Control of packets

In this section, we discuss remaining issues of the
OpenFlow-based packet forwarder. As we mentioned in sec-
tion III, all IP packets are controlled by the OpenFlow protocol.
The packets of other protocols such as Address Resolution
Protocol (ARP) are treated as follows in this implementation.
ARP packets from the external connection is sent to both the
real and honey server and ARP packets from the real/honey
server are forwarded to the external connection. This may
occur conflicts. This makes a possibility that an attacker can
be aware of something unusual.

The other issue is caused of our isolation. Since the honey
web server is isolated to the real web server and its surrounding
systems, and hence, this leads an attacker to feel different.
Even if the attacker intends to use this web server as a step
stone of other attacks, our isolation prohibits the attacker to
launch another attack from the isolated server.

The way for dealing with these problems are beyond
the work of this paper. In these problems, we assumed that
the attacker can successfully gain control for injecting OS
commands. In this case, it can be regarded that the honeypot
usually has already finished its role. From the viewpoint of
collecting new vulnerabilities in web applications, these issue
were not critical to meet with deception ability.

VIII. CONCLUSION

The paper introduced INTERCEPT+, a component of the
honeypot for web applications. To meet the requirements of
the honeypot, we explored the suitable solution and discovered
the missing piece, which can avoid the data corruption as
well as finishing the migration in short time period. While
we employed server-type and high-interaction as a honeypot
architecture, the honeypot system created the perfect copy of
the actual system. Hence the honeypot had the same memory
and disk content of the actual system, web attackers would not
be aware of that they were forwarded to honeypot even they
checked any TCP and/or web sessions.

We also surveyed several solutions of virtual machine
environments and developed our own virtual machine systems.
At first, we chose QEMU and modified its source codes,
and used the incremental live block migration for creating
honey web server. Next, we employed AUFS instead of using
incremental live block migration in order to reduce the time for
completing live block migration. Further, we modified Kemari
and its fault tolerance feature, to reduce the time of the memory
migration. We also observed that the creation of the honey
web server could be done in few seconds when the size of the
snapshot was reasonable.

We finally implemented an OpenFlow-based packet for-
warder. Even if our live migration approach arose address
duplication, we verified that our implementation could forward
the packet to the suitable destination regardless of the duplica-
ted address. We also evaluated its performance and measured
the effectiveness. The result showed that we could correctly
control the attack and normal packets to our honeypot system.

The rest of work is to improve the performance of our
developed INTERCEPT+. There still remains the problem,
I.e., the difference of the temporal requirements, but we will
develop the suitable honeypot for web applications regarding
to the rapid migration techniques in our future work.

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REFERENCES

reading-room/whitepapers/application/web-based-attacks-2053, The

www.mcafee.com/en/resources/audio/foundstone/websec101-intro.html,

lication Security Risks,” The Open Web Application Security Project,

Matters,” Available at: http://www.sans.org/reading-room/whitepapers/
securecode/sql-injection-modes-attack-defence-matters-23, The SANS

at: http://www.sans.org/reading-room/whitepapers/securecode/
web-developers-guide-cross-site-scripting-988, The SANS Institute,

web application attacks,” Available at: http://www.sans.org/reading-room/whitepapers/
web-application-firewall-detect-block-common-web-application-attacks-33831,

[7] M. Dermann, M. Dziadzka, B. Hemkemeier, A. Hoffmann, A. Meisel,
Firewalls,” The Open Web Application Security Project, Tech. Rep.,
2008.

[8] D. Miyamoto, S. Teramura, and M. Nakayama, “INTERCEPT: High-
interaction Server-type Honeypot based on Live Migration,” in Proceed-
ings of the 7th International ICST Conference on Simulation Tools and
Techniques, Mar 2014.


pots,” in IEEE Conference on Detection of Intrusions and Malware &
Vulnerability Assessment, Jul 2005.

Security,” World Academy of Science, Engineering and Technology,


client-honeynet.org/.


