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A VMM-Based Intrusion Prevention System in Cloud Computing Environment

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Abstract—Nowadays, cloud computing has become a preferred solution for start-up businesses and corporations. Unfortunately, cloud computing user usually does not pay attention to security aspect of cloud services. Cloud computing security is a mandatory requirement that must be fulfilled by the cloud provider. One of the solution for improving the security aspect of cloud computing services is using Network-based Intrusion Detection System (NIDS). NIDS detects and monitors attacks through the network. The signature-based method in NIDS performs identification data packet through network. In this research, the authors designed, implemented and evaluated the performance of configured NIDS. The authors also perform analysis of the result and performance evaluation of NIDS on OpenStack private cloud. The aim of this research is to evaluate the NIDS performance and its accuracy in classifying attacks. The results reveal that the model is functioning securely and accurately. Moreover, the real-time alert of NIDS is able to detect the classified attacks through network successfully.

Keywords:—Cloud Computing, Security, Intrusion Detection, Attacks, Masquerade.

1. INTRODUCTION

Cloud computing has a broad appeal because it enables IT managers to provision services to users faster and in a cost-effective way. However, it does raise some concerns and chief among them is securing data in the cloud because of their operational models, the enabling technologies, and their distributed nature, clouds are easy targets for intruders. While intrusions can be handled by an Intrusion Detection System (IDS) [1], current IDSs have many deficiencies which hinder their adoption in a cloud environment. This paper describes CIDS, a framework for a Cloud based Intrusion Detection System to deal with attacks like: (1) Masquerade

attacks: where threats impersonate legitimate users, (2) Host-based attacks: these can be a consequence of masquerade attacks and generally result in an observable user behavior anomaly and (3) Network-based attacks. CIDS also summarizes the intensive network based IDS alerts according to the attack signature and target. Section 2 briefly introduces a cloud security and the seven known top threats to cloud computing systems. Then, it classifies vulnerabilities of the cloud computing paradigm. The next section surveys the related works. Section 4 describes the components, architecture, detection models, and advantages of our CIDS framework. Section 5 outlines future work.

2. CLOUD COMPUTING SECURITY

Threats of cloud computing systems differ from those of traditional IT solutions. CSA (Cloud Security Alliance)[2] ranks seven threats that apply across cloud computing SPI models [3]: (1) Abuse and nefarious use of cloud computing, (2) Insecure interfaces and APIs, (3) Malicious insiders, (4) Shared technology issues, (5) Data loss or leakage, (6) Account or service hijacking, (7) Unknown risk profile. [4] defines seven risks a user should raise before committing: (1) Sensitive data should be processed outside the enterprise only with the assurance that they are only accessible and propagated to privileged users, (2) One customer data should be fully segregated from those of another customer, (3) A customer needs to verify if the infrastructure complies with some regulatory security requirements, (4) The cloud provider should commit to store and process data in specific jurisdictions and obey local privacy requirements on behalf of the customer who do not know where data is stored, (5) The cloud provider should offer replication and disaster recovery mechanisms, (6) Investigative support needs to be ensured, (7) Data should be accessible even when the provider is acquired by another company or if the user moves to another provider.

3. RELATED WORK

IDSs may be classified according to the source of data into: (1) Host-based IDS (HIDS), where sensors that detect an intrusion are focused on a single host. (2) Network-based IDS (NIDS), where sensors are focused on a network segment. (3) Distributed IDS (DIDS) which integrates both types of sensors, DIDS can be categorized as Mobile Agent IDS (MAIDS), Grid based IDS (GIDS), and recently Cloud based IDS. Traditional NIDS and HIDS cannot identify suspicious activities in a cloud environment. As an example, a NIDS can not detect an attack anytime node communication is encrypted. Attacks can also be invisible to HIDS, because they may not leave traces in the node operating system where the IDS resides. Since in clouds, distinct users share computing and communication resources, attacks may be originated from and be directed against several resources within the cloud infrastructure. Hence, only a distributed strategy may be appropriate. The adoption of DIDS solutions [5] is still challenging in cloud computing because the complex architecture of the infrastructure and the distinct kinds of users lead to different requirements and possibilities for being secured. Some of these IDSs are scalable but they have the problem of single point of failure as most-distributed hierarchical IDS. Also, some distributed IDSs are strongly centralized and lack the flexibility to be applied to different cloud architectures. This category of IDSs can not respond to attacks against the IDS itself, another deficiency is that some IDSs use only one technique for detecting the attacks, whether, the knowledge based technique or the behavior-based one. A good IDS should integrate them to detect known and unknown attacks with a reasonable false alarm rates. Mobile Agent-based IDSs [6] are not a suitable solution for clouds, because their hierarchical structure poses both reliability and scalability problems. Furthermore, they are not flexible and can not respond to attacks against the intrusion detection system itself. Other

problems are recalled in [6]. GIDS solutions in [7, 8 9, 10, 11, 12, 13,14] offer a partial or complete methodology for dealing with attacks against the processes running either inside or outside the kernel space, and Grid protocol stack and network devices. However GIDS solutions can not be adopted because of: (1) Distinct cloud service models, SaaS, PaaS, and IaaS, with different types of threats and distinct users with distinct requirements, (2) The high scalability of cloud systems, (3) GIDS solutions do not correlate the alerts coming from different nodes, and (4) The performance and the load balancing inside cloud network are higher than in grid systems. Some cloud based intrusion detection systems have recently been proposed. [15] proposes an IDS based on the Mobile Agents (MAs) technology. The most important deficiencies are the performance and the security issues related to MAs [16, 17]. [18] proposes a theoretical framework for dealing with attacks targeting any service model but it does not correlate the alerts from components in the cloud infrastructure. The analysis of previous work confirms that, a proper defense strategy for cloud systems needs to: (1) Be distributed and scalable to adapt the cloud characteristics, (2) Avoid any single point of failure, (3) Protect the IDS by isolating it from vulnerabilities in the host machine, (4) Have a flexible architecture to be applied to several cloud architectures, (5) Integrate both behavior and knowledge based techniques, and (6) consider different service models and user requirements.

4. THE PROPOSED FRAMEWORK (CIDS)

CIDS has a scalable and elastic architecture with a P2P solution and no central coordinator. Hence, there is no single point of failure. CIDS architecture distributes the processing load at several cloud locations and isolates the user tasks from the cloud by executing them in a monitored virtual machine. This helps in protecting CIDS components from threats that can control a task in the VM and that can modify CIDS

components. To increase attack coverage, CIDS integrates knowledge techniques and behavior based ones. Furthermore, it collects events and audits from VMs so that the detector and correlator components can analyze them. Each node also includes an audit system that monitors messages among nodes and the middleware logging system, and collects events and logs from the VMs. By sharing both the knowledge and behavior databases in each node among the audit components, CIDS can detect the masqueraders that access from several nodes and both host-based and network-based attacks. Furthermore, to take into account the large volume of data in a cloud that prevents administrators from observing any action, a further CIDS component parses and summarizes a highly intensive number of alerts from a NIDS component in a physical or virtual switch inside the cloud virtual network. A report for the administrators collects alert messages from all IDS detectors installed in the cloud system. CIDS resides inside the cloud middleware which provides a homogeneous environment for accessing all nodes. The middleware sets the access control policies and supports a service-oriented environment. Since the middleware can be install inside different grid and cloud systems, CIDS can be applied to several Grid and cloud systems.

4.1 CIDS Architecture

In the proposed architecture, each node has two IDSs detectors, CIDS and HIDS. In this way, the node can cooperatively participate in intrusion detection by identifying the local events that could represent security violations and by exchanging its audit data with other nodes. Figure 1 shows the sharing of information among the following CIDS components:

Cloud Nodes: Contains the resources homogeneously accessed through the cloud middleware.

Guest task: it is a sequence of actions and commands submitted by a user to an instance of VM.

Logs & Audit Collector: it acts as a sensor for both CIDS and HIDS detectors and collects logs, audit data, and sequence of user actions and commands.

VM: it encapsulates the system to be monitored using VMM. The detection mechanisms are implemented outside the VM, i.e. out of reach of intruders. A single instance of a VM monitors can observe several VMs.

Type II Virtual Machine Monitor (*VMM*): CIDS uses type II VMM [19] implemented as a process of an underlying operating system of the host machine. Some VMMs are useful in system security, among them: Isolation, Inspection, and Interposition [19]. VMM stores in the audit system the data collected by the logs & audit collector component and forwards them to both CIDS and HIDS correlator components.

The Audit System: this component implements three main functions. First of all, it monitors message exchanges among nodes and extracts from them the behavior of the cloud user. Then, it monitors the middleware logging system in the node itself. CIDS can collect all audit data and middleware events such as user's login or logout from the cloud system or tasks submissions. The third function collects and stores events and logs from the VM system. A log entry is created for each node action with the action's type, (e.g. error, alert, or warning), the event that generated it, and the message.

CIDS Correlator and Detector: it correlates user behaviors, e.g. sequence of commands or actions collected from several sources, and analyzes them through our new heuristic semi-global alignment approach (HSGAA). We will briefly explain later the HSGAA approach in CIDS.

HIDS correlator and detector: it correlates user's logs and signatures collected from several sources. Then it analyses them to detect known trails left by attacks or predefined sequences of user actions that might represent an attack. It is implemented by the OSSEC IDS tool [20] that receives user's logs and signatures and determines whether a rule in the knowledge based database is being broken. After that, it computes the probability that a user action represents an attack, and it communicates this to the alert system that alerts the other nodes if the probability is sufficiently high.

Behavior-Based Database: it is a profile history database for the behavior of cloud users. It is important that all nodes share the same behaviour database for the same user. This helps in correlating the normal behaviors of a specific user to detect a suspected behavior distributed among several nodes. Since behavior deviation in one node can be normal in another one, correlation reduces the false alarms rate and it is more suitable for adapting the deployment and utilization of the cloud system, as a user task can be executed in more than one machine. Access to all databases, including events collected by the VMM from the VMs, can be easily implemented by the middleware that transparently creates a virtual homogeneous environment and synchronizes the nodes. As an example, consider that the audit system can create a log entry such as: "User Roy only logs in for 2 to 3 hours and uses a specific sequence of UNIX commands", only if the nodes know the behavior of the user in all the nodes.

Knowledge-Based Database: it stores a set of rules and signatures for known attacks. It describes a malicious behavior with a rule to be compared against those in the database. Like the behavior-based database, all nodes should share or exchange the same knowledge base, through the services provided by the middleware.

Alert System: it uses the middleware's communication mechanisms to alert other nodes if the CIDS or HIDS correlator and detector components signal an attack. It also

communicates its alerts to the report producer component in the scheduler machine.

***Parser and summarizer*:** It parses and summarizes the alerts fired by a component in the cloud virtual network. We will briefly explain later, the adopted algorithm.

***Report producer*:** it collects alerts from any cloud IDS and sends a report about attacks to the cloud scheduler. It helps also service providers to know if their infrastructure is exploited to penetrate other victims.
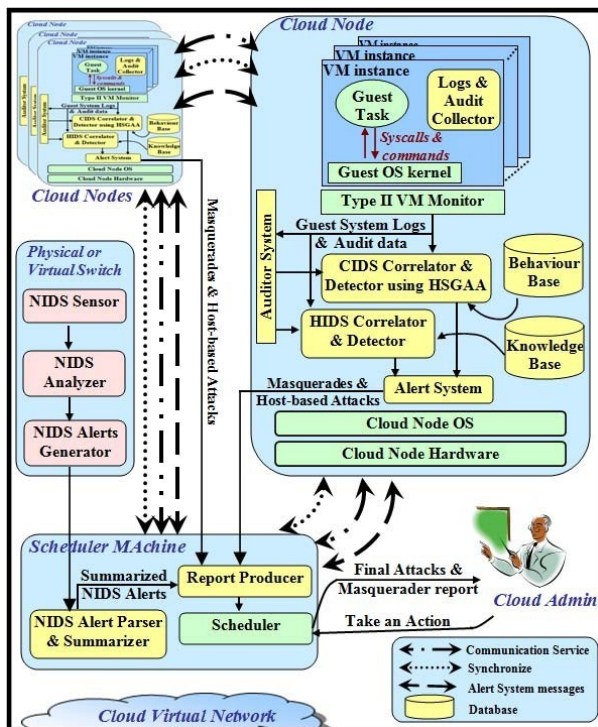

Figure.1: CIDS Architecture Yellow components are CIDS components, Green ones are cloud system components, and Pink ones are NIDS components

4.2 CIDS Deployment Models

We recall the P2P architecture of CIDS helps in balancing the load among all nodes. In CIDS each node has its own analyzer and detector components that are connected to the behavior and knowledge based databases. The individual analysis reduces the complexity and the volume of exchanged data, but at the expense of the node processing overhead. As discussed in the following, our approach can reduce this overhead. The lack of a single point of failure also improves the framework

attack resistibility. Some components of the scheduler machine (i.e., Report Producer and NIDS Alert Parser and Summarizer) do not represent a single point of failure. As a matter of fact, a cloud runs several copies of the scheduler node with a fault tolerance technique provided by the middleware to backup the processing data. According to the architecture of the cloud system, CIDS components can be deployed into one of two models namely, hybrid and pure P2P models. In the hybrid model, each node communicates to nodes outside its domain through its domain controller i.e., nodes in different domain are not directly connected. Whereas, in the pure P2P model, each node communicates directly to other nodes i.e., the domain controllers acts like a peer but with a scheduler to perform the scheduling tasks.

4.2 CIDS DEPLOYMENT MODELS

We recall again, CIDS framework has P2P architecture with no central coordinator, where the network load is symmetrically distributed to all nodes. In CIDS each node has its own analyzer and detector components that are connected to the behavior and knowledge based databases. This differs from distributed centralized IDSs, where a centralized management system collects all the data. The individual analysis reduces the complexity and the volume of data exchanged among nodes, but at the same time it increases the processing overhead inside a single node. We will explain later, how our HSGAA approach can reduce this overhead. Since CIDS has no single point of failure, the framework represents a moderate solution for attack resistibility. The cloud scheduler machine has some components (i.e., Report Producer and NIDS Alert Parser and Summarizer) that do not represent a single point of failure, because there are several copies of the scheduler node in the cloud with a fault tolerance technique provided by the middleware to backup the processing data. According to the architecture of the cloud system, CIDS components can be deployed into one of two models namely, hybrid and

pure P2P models. In the hybrid model, each node communicates to any other node outside its domain through its domain controller i.e., no direct connection between two nodes in different domain. Whereas, in the pure P2P model, each node communicates directly to other nodes without using the domain controller i.e., the domain controllers work like the other peers but with a scheduler to perform the scheduling tasks.

4.3 Attacks and Services Covered by CIDS

CIDS is a defense strategy that satisfies the previous IDS requirements and deals with some attacks against SaaS, PaaS and IaaS clouds.
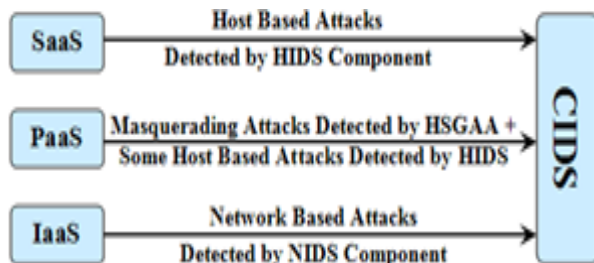

Figure.2: Attacks and services covered by CIDS.

Figure 2 shows the attacks and services discussed in the following:

1) Masquerading attacks:

This is a PaaS attack that includes any attack that impersonates a legitimate user to use service resources maliciously. This is by far the most critical attack, as its exploitation is rather easy. An intruder masquerades as a legal user by obtaining the user's password and this leaves some trails left at the service location. CIDS detects this attack through HSGAA.

Heuristic Semi-Global Alignment Approach (HSGAA):

It detects masquerade attacks based on the Semi-Global Smith Waterman alignment algorithm [21]. The main idea underlying HSGAA is to compute the best alignment score, by aligning the active user's session sequence (e.g., mouse movements, system calls, opened windows titles, written Commands, opened file names) to the previous stored sequences for this user. By properly defining the misalignment areas, we can label them to be anomalous. The presence of several anomalous areas is a strong indicator of masquerade attacks. The value of HSGAA is its ability to align sequences not only using lexical matching, such as string matching or longest common substring searches. Furthermore, it allows for small mutations in the sequences with small changes in the low-level representation of the commands functionality (e.g., using vi instead of cat in UNIX command line interface).

From the computational point, HSGAA accelerates the detection and update operations, by implementing these operations in distinct threads. As a further improvement, the heuristic approach divides the signature sequence into a smaller set of overlapped subsequences to reduce the computational load of the alignment process. This also results in shorter masquerader live time inside the system.

From the security point, unlike traditional semi-global alignment algorithm that uses the same parameters for all users, HSGAA can reduce both false positive and false negative rates by pairing each user with distinct scoring parameters. This increases the hit ratio of the detection system. Furthermore, it supports two update modules that support the slight changes in the user behavior due to some project requirements or other individual considerations. HSGAA provides two scoring systems that enable changes in the low-level representation of the commands functionality, by categorizing user's commands to a set of groups and enabling the alignment of commands in the same group without reducing the alignment score.

2) Host-based attacks:

Host based attacks may be a consequence of a masquerading attack. CIDS detects several host based attacks using the current HIDS tools, which integrate both the

log analysis and data mining techniques into a log mining technique. As previously mentioned, we use OSSEC [20] as an example of HIDS tools.

3) Network-based attacks and the summarizer and log analyzer component:

CIDS detects network attacks by analyzing network packets using NIDS tools. We use Snort [25] as NIDS. The summarizer and log analyzer component analyzes and summarizes NIDS alerts and logs, and sends a report to the cloud administrator. This component is an IDS service supported in the IaaS model and works as outlined below.

Parser and Summarizer Approach:

from the point of view of the cloud administrator, a clear, summarized, and readable alarm report is fundamental. A NIDS component produces an intensive number of alerts, because of the high scalability of the cloud network. Our parser and summarizer component reduces the number of alerts for the cloud administrator. Among the approaches to summarize and integrate NIDS alerts, we recall, [22, 23]. A more suitable and clear approach to store NIDS alerts is [24] that is based upon the alert parameters shown in Table 1. Our approach is based upon the idea that, if one or more hosts, are attacking the same machine using the same attack signature, we should reduce the intensive redundant alerts fired by NIDS components. This can be achieved by merging all the alerts with the same combination (destination IP, attack signature) into one alert only that also merges their attributes. Our implementation uses SNORT with MySQL. Table 1 shows an example.

Table.1: An Example for the Alert Description Table.

Alert ID	Destination IP	Signature ID	Alert Description							
			Signature Name	Signature Class ID	Signature Priority	Source IP	IP Protocol	Source Port	Destination Port
A1	1.2.3.4	11	DOS	1	3	1.1.2.3	TCP/IP	50	70
A2	1.2.3.8	13	Rootkit	3	5	1.2.3.3	TCP/IP	20	60
A3	1.2.3.8	13	Rootkit	3	5	1.2.3.7	TCP/IP	30	72
A4	1.2.3.4	11	DOS	1	3	1.1.2.3	TCP/IP	50	70
A5	1.2.3.12	13	Rootkit	3	5	1.2.3.6	TCP/IP	122	17
A6	1.2.3.4	11	DOS	1	3	1.1.2.3	TCP/IP	50	70
A7	1.2.3.12	14	Buffer Overflow	2	4	1.1.2.4	TCP/IP	152	23
A8	1.2.3.8	13	Rootkit	3	5	1.2.3.3	TCP/IP	30	82

Our approach neglects the source IP address because it can be spoofed. Spoofing can be detected by the HIDS component. However, the final summarized table would contain all information that describes the attack including the source IP address that can be used later by the cloud administrator.

Table.2: The Final Alerts Summarization Table.

Alert ID	Destination IP	Signature ID	Alert Description							
			Signature Name	Signature Class ID	Signature Priority	Source IP	IP Protocol	Source Port	Destination Port
S1	1.2.3.4	11	DOS	1	3	1.1.2.3	TCP/IP	50	70
S2	1.2.3.8	13	Rootkit	3	5	1.2.3.3, 1.2.3.7	TCP/IP	20 30	60, 72, 82
S3	1.2.3.12	13	Rootkit	3	5	1.2.3.6	TCP/IP	122	17
S4	1.2.3.12	14	Buffer Overflow	2	4	1.1.2.4	TCP/IP	152	23

Table 2 shows the final alerts produced by our approach, we note that alerts A1, A4, and A6 refer to the same signature, their attacks targets the same machine and the attacker uses the same method three times. The alerts are summarized by alert S1. The alerts A2, A3, and A8 have the same signature but with different signature details.

The attackers fired these attacks from two different host machines. These alerts are summarized to alert S2 in Table 2. Finally, the attacks related to the alerts A5 and A7 target the same machine but with different signatures, hence these alerts have not been

summarized. Algorithm1 shows the parsing and summarization.

Algorithm1: Parsing and Summarization

01: Begin

02: Build Table T with rows= n //This table is similar to table 1.

03: Define:

dest-ip=1, sig-id=2,

i=1, // Index for rows of table T

alert-dscrp-strct = T(1)(signature-name, signature-class-id, signature- priority, score-ip, ip-protocol, source-port, destination-port) // Is a structure contains one record of table T with 7 columns of alert description (from 4 to 10 of Table 1),

summarized-T: // This table is similar to table 2.

04: While (Length(T) >1 and i < Length(T))

05: For j=i+1 to Length(T) do

06: If ((T(i, dest-ip) = T(j, dest-ip)) And (T(i, sig-id) =T(j, sig-id))

And (T(i, alert-descrp-strct) = T(j, alert-descrp-strct)))Then

07: Add the i$_{th}$ record to table summarized-T

08: Delete the i$_{th}$ and the j$_{th}$ records from table T, set i=1

09: Else

10: If ((T(i, dest-ip)=T(j, dest-ip)) And (T(i, sig-id) =T(j, sig-id))

And (T(i,alert-descrp-strct)!=T(j, alert-descrp-strct))) Then

11: Merge the i$_{th}$ and the j$_{th}$records of table T and add the resultant merged record to table summarized-T

12: Delete the i$_{th}$ and the j$_{th}$ records from table T, set i=1

13: End If

14: End If

15: End For

16: i=i+1

17: End While

18: If (T is not Empty)

19: Add table T to table summarized-T

20: End IF

21: Return (summarized-T)

22: End

4.4 CIDS Detection Models

In the following, we describe the three alternative models to detect masquerade and host-based attacks namely: (A) Audit exchange model, (B) Audit exchange model with a neural network, and (C) Independent model.

A) Audit exchange model

In this model, nodes exchange their audit data among each others so that each one has a complete audit data for its current users. The detection phase depends on two parameters: (1) The alignment score computed in the CIDS detector component, (2) Alerts fired by the HIDS component. In this way, the detection overhead is balanced among nodes with no single point of failure. The detection efficiency is high because the user audit is concentrated in one place and the masquerader surviving is very short. As a counterpart, this model needs a fast periodic update of user audit data in all the nodes related to the user and this introduces some overhead in the cloud network. The processing steps are:

5. CONCLUSION AND FUTURE WORK:

Cloud computing risks and threats differ from traditional ones and current IDS technology is not suitable for cloud computing. This paper has proposed CIDS framework to define a proper defense strategy for cloud systems. CIDS is a scalable and elastic solution with P2P architecture with no central coordinator that avoids a single point of

failure. CIDS has two P2P deployment models hybrid P2P and pure P2P. To increase flexibility and portability, the middleware where the framework resides can be installed in distinct cloud and grid systems. To increase attacks coverage, CIDS integrates knowledge-based and behavior-based approaches and monitors each node to identify local events that could represent security violations. When an attack occurs, it alerts other nodes. CIDS exploits the distinct execution spaces of a VMM to separate the intrusion detection system from the system under monitoring so that the intrusion detector components become invisible and inaccessible to intruders. CIDS includes an audit system to discover those attacks that network-based and host- based systems cannot detect. It also parses and summarizes a high intensive number of alerts fired by NIDS component to prepare a readable report for the cloud administrator. CIDS provides three alternative detection models. The CIDS webpage [27] describes further details about CIDS.

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