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Forensics framework for cloud computing[☆]

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ABSTRACT

The popularity of cloud computing has been on the rise in recent years, as cloud resources are not only shared by many users but can be allocated on demand. A recent survey reports success of the cyber criminals in using cloud computing technology for fraudulent activities, due to its essential characteristics and the lack of suitable digital forensic techniques for the cloud environment. While mitigating cloud crime, investigators face several challenges and issues dealing with cloud forensics. In this paper, the challenges faced by forensic investigators are highlighted. Most of the research work deals with the identification of challenges in cloud forensics and the proposed solutions reported in literature depends on Cloud Service Provider (CSP) for forensic investigation. The dependence on CSP includes the collection of data for the forensics process and there may be a chance of altering data that affects the entire investigation process. For mitigating the dependency on CSP, a new model for collecting forensic evidence outside the cloud environment is developed.

1. Introduction

1.1. Cloud forensics

National Institute of Standards and Technology (NIST) [1] defines cloud computing as “Cloud computing forensic science is the application of scientific principles, technological practices and derived and proven methods to reconstruct past cloud computing events. This is done through identification, collection, preservation, examination, and interpretation and reporting of digital evidence”. Ruan et al. [2] have defined cloud forensics as “the application of digital forensic science in cloud environments as a subset of network forensics”, as shown in Fig. 1. Here, the authors highlight the significance of cloud forensics in three different aspects, namely, technical, organizational and legal. Technical aspects are engaged in forensic tools, mechanisms, and procedures. Organizational aspects incorporate the interaction between cloud actors for forensic investigation. Legal aspects deal with multi-jurisdictional and multi-tenant situations. The authors also identify cloud forensics as an associate of cloud computing and digital forensics.

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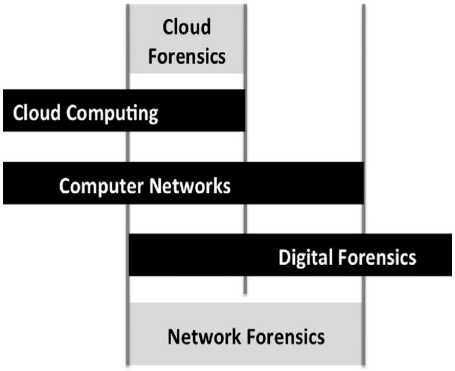

Fig. 1. Cloud forensics [2].

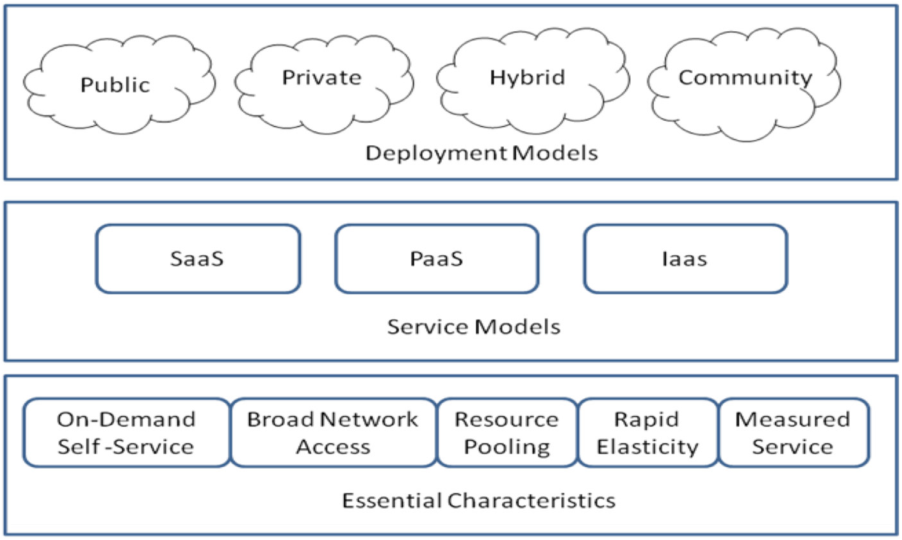

Fig. 2. NIST cloud model [3].

1.2. Cloud computing

The term cloud computing means sharing of computer resources among different users. As per NIST [3] "Cloud computing is 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". The cloud model consists of five essential characters, namely**,** on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service, and three service models, namely: Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS), and four deployment models such as Public Cloud, Private Cloud, Hybrid Cloud, Community Cloud [3] as depicted in Fig. 2.

1.3. Digital forensics

Digital Forensics refers to "an applied science to identify an incident, collection, examination, and analysis of evidence data" [1]. The different phases of digital forensics are**:**

- Identification: Two major steps are involved in this phase, (i.e.) identification of malicious activity and isolating the evidence towards malicious activity.
- Collection: Evidences related to the malicious activity from different digital media are collected and the integrity of the evidence is maintained.
- Organization: In this phase, the examiner investigates the collected evidence which forms the examination phase and all identified evidence are correlated in the context of the malicious activity.
- Presentation: The investigator produces an organized report to the jury in the context of his investigation towards the case.

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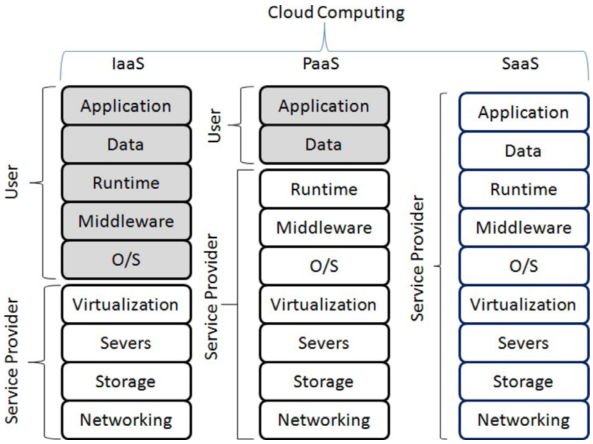

Fig. 3. Access control to the service models [23].

The rest of the paper is organized as follows. Challenges faced in cloud forensics are discussed in Section 2. The various relevant solutions in the literature are highlighted in Section 3. The limitation in current solutions and the proposed solution for mitigating those challenges are discussed in Section 4. Experimental setup for the proposed work and the inferences are depicted in Sections 5 and 6 respectively. Finally, conclusions are discussed in Section 7.

2. Challenges in cloud forensics

2.1. Data acquisition

This is the fundamental and vital step in the forensic procedure. Any flaw in this phase is passed on to the successive phases, resulting in transformation of the course of the investigation process. In digital forensics, investigators get hold of the affected computer (digital equipment) and carry out the investigation process by applying forensic principles in search of evidence towards malicious activity, to ensure no alteration in the evidence. But, in cloud forensics, grabbing the equipment is infeasible owing to the multi-tenancy and remote nature of cloud computing. Birk [4] indicates that the evidence may be in three different states in cloud, namely, at rest, in motion, and in execution. This will complicate the data acquisition compared to traditional forensics. Some of the challenges faced by the investigators towards data acquisition in a cloud environment are as follows.

2.1.1. Physical inaccessibility

Evidences are scattered and saved in different locations due to the significant characteristics of cloud. This leads to inaccessibility towards the collection of data and affects the data acquisition process.

2.1.2. Less control in cloud

In cloud, both users and investigators have restricted access, unlike digital forensics seizing of digital equipment is uncertain in the cloud. This complicates the data acquisition process in the cloud environment. The access control to the cloud varies by service models as shown in Fig. 3.

Only logs related to the application can be accessed by the investigator in the SaaS and PaaS models. In PaaS, application can be built by customers for getting certain additional forensics information compared to SaaS model, which has very limited access. Customers can move up to the operating system level in the IaaS model. IaaS has more privileges compared to the other two models. Even though access control is available for various levels in the cloud, forensics investigators have to anticipate Cloud Service Provider (CSP) for collecting data. J. Dykstra and A. Sherman quote the data acquisition problem by a hypothetical case study of child pornography [5]. In this case study, the authors have addressed the warrant issue, i.e. the location must be specified in the warrant, but the data is scattered and stored in various locations in the cloud. A cloud server cannot be seized by the investigator despite reaching the location due to its multi-tenant nature.

2.1.3. Volatile data

Virtual Machines (VM) are used by service providers for provisioning their customers. In this VM, volatile data like registry entries or temporary internet files will be lost if it is not synchronized with storage devices like Amazon S3, i.e. all information in VM is erased when VM gets restarted or shutdown [6].

2.1.4. Trust issue

Another serious problem is the dependence on the third party for collecting evidence in the cloud [8]. This issue is pointed out in a child Pornography case after a search warrant was issued. The investigator needs an internal staff to assist him in collecting data. Sometimes this person may be from the same CSP or may not be a certified investigator and this may affect the integrity of data to be produced in law.

2.1.5. Multi-tenancy

In cloud computing, different clients share individual resources. While acquiring evidence from cloud**,** two issues are addressed by the investigator. To start with, he has to prove that the extracted data is not mingled with other's data and has to maintain the integrity of the other user's data.

2.2. Logging

Analysis of logs is the first step in digital forensics. The logs may be process logs, application logs, system logs or network logs. These are the key for the investigation process, but getting this log data from the cloud is a crucial one. Several challenges that are recognized while obtaining logs are as follows [7–9].

2.2.1. Decentralization

In cloud, the logs are spread all over the network. Due to this phenomenon, the gathering of logs from various sources becomes difficult for cloud investigators.

2.2.2. The volatility of logs

Virtual Machines are used by CSPs for providing service to their customers. In the case of VMs, the volatile data like temporary internet files, registry data is completely lost once VM gets restarted or shutdown.

2.2.3. Accessibility of logs

There is no procedure or method for accessing logs in distinct places and the logs are used for troubleshooting, debugging, etc.

2.3. Dependence on CSP

Logs are collected and stored at CSP premises requiring the need for the investigators and the users to depend on CSPs for accessing network logs and server logs. In this point, CSP may tamper logs.

2.4. Chain of custody

Chain of custody is "the chronology of the ownership, custody or location of a historical object, document or group of documents" [10]. This is one of the most significant issues in forensic investigation, clearly indicating when and how the evidence was collected, analyzed, organized and presented in court [11]. Application of this procedure in digital forensics is easier than that of cloud forensics since seizing of equipment is possible in digital forensics. In the case of cloud forensics, this is not applicable because of its multi-jurisdictional laws and procedures. Hence a chain of custody produces many challenges [12,13] in cloud forensics. In a hypothetical case study of compromised cloud-based website, J. Dykstra and A. Sherman have highlighted the access available for multiple users to evidence. So, investigators have to depend on CSP for acquiring the chain of custody [5]. Birk et al. queried the reliability of hypervisor for a chain of custody [4].

2.5. Crime scene reconstruction

Crime scene reconstruction is infeasible in a cloud environment as data in VM gets erased completely when VM gets power off or rebooted [14].

2.6. Cross border law

Data centers afforded by cloud providers are distributed worldwide, so the cross-border law is an important issue in cloud forensics. The investigation process should be carried under the laws in the specific jury, whereas the measures for preserving data and chain of custody differ according to the jury and the entire investigation process will be affected by the cross-border law.

2.7. Law presentation

Presentation under jury is the final step in both digital and cloud forensics. In a cloud environment, thousands of VMs run in cloud data centers and hundreds of users are accessing simultaneously. This creates a serious challenge in cloud forensics than digital forensics [14].

3. Related works

This section highlights, the various solutions discussed by researchers for mitigating the challenges in cloud forensics are highlighted.

Dykstra et al. [5] have projected the use of cloud management plane in IaaS model. In this model cloud users and investigators have to trust the management plane to obtain data for investigation. Management plane in cloud premises makes the investigation process complex, but it mitigates the dependence of CSP.

Brik et al. [6] have recommended the use of application programming interface (API) to enable access log information to customers by read-only API, and the customer can provide information for the forensic investigation. Trusted third party issue was solved by this solution since customers are directly involved in continuous synchronization. But the dependency of CSP still exists and the authors have also suggested the encryption of logs before sending to the API for defending external breaches.

Marty [9] has suggested some guidelines for gathering logs which are used for forensics investigation. The author proposed a logging framework to solve logging issues that help in developing business oriented log framework which will be used by various IT professionals. SaaS model gets benefited by this framework.

Dykstra et al. [15] have offered a six layer trust model for mitigating the dependency of CSP and to preserve the trust. In this model, investigators have to trust resultant layers alone. IaaS model gets benefited from this model. Trust in individual layers and PaaS model is not discussed.

Wolthusen [16] suggest interacting evidence presentation and visualization mechanism for mitigating the dependence on CSP by granting confidence and trust. This model depends on CSP for getting access to the collected data as it is operated within the cloud and works for IaaS and PaaS models.

Zafarullah et al. [17] have proposed a solution inside cloud premises in IaaS model for getting OS logs and security logs. In this solution, distributed denial of service (DDoS) attack is launched in an eucalyptus environment. The service type and attacking machine IP are identified by logs in the eucalyptus. Dependence on CSP still exists since the solution is implemented inside the cloud premises. The authors conclude that the CSPs have to adopt a new mechanism for taking cloud forensics to a new extent.

Biggs et al. [18] have presented a universal law called global unity solution for cloud forensics investigation. This solution facilitates the investigation process, which solves Cross-Border law issue. For implementing this solution, all cloud providers have to adopt global unity solution.

Shah et al. [19] have highlighted the challenges and a possible malicious activity in cloud computing. The authors propose a three-layer architecture for cloud forensics. In this approach, the investigator has to depend on CSP for getting data.

Khorshed et al. [20] have highlighted the major threats in cloud computing and proposed a Support Vector Machine (SVM) technique performance based on kernels. They have created an attack set and compared it with other convenient machine learning techniques. Possible threats in the cloud are identified by this model, but predefined attacks are alone detected by this method.

Hale [21] has highlighted digital artifacts and procedures for forensic investigation that have to be followed by the investigator in Amazon cloud. Dependence on CSP exists for collecting evidence for the investigation.

Ruen et al. [22] have suggested the necessary things to be focused on cloud computing after conducting a survey over 257 respondents. Definition of cloud computing, cloud forensics, the significance of cloud, challenges, and opportunities of cloud forensics and research directions are included in this survey. Forensics as a Service is suggested by 55% of respondents and recommended by 87% of respondents.

4. Proposed solution

All previously identified solutions can be implemented only in cloud premises and investigators must depend on CSP for collecting forensic data for investigation. To overcome these limitations the proposed solution is implemented outside the cloud premises.

The proposed solution addresses the data collection issues discussed in literature by introducing a centralized forensic server and a forensic layer called forensic monitoring plane (FMP) outside the cloud Infrastructure, after obtaining permission from the international telecommunication union (ITU). So, the investigators need not depend on the CSP for collecting data.

The proposed model [24] for cloud forensics is shown in Fig. 4.1, where forensic monitoring plane (FMP) and forensic server are introduced for enhancing cloud forensics. The forensics tool such as forensic toolkit (FTK) analyzer, E-Detection running at the top of the FMP will monitor entire inbound and outbound connections in a cloud environment and the monitored data are forensically imaged (i.e.) bit by bit stream encryption and is stored in separate forensics server which is located in cybercrime premises. The forensic tool also monitors the actions of cloud service models. The tool automatically acquire**s** a forensic image of a current state in cloud service models which include VM and stores it in separate forensics server.

Hence all the actions, including network traffic in the specific cloud are forensically imaged whenever an event occurs, or the request processed in the cloud is acquired and is again encrypted and stored in the forensic server to enable reduction in the trust amount on CSP. The forensically imaged data is unaltered since bit by bit stream imaging is done during the

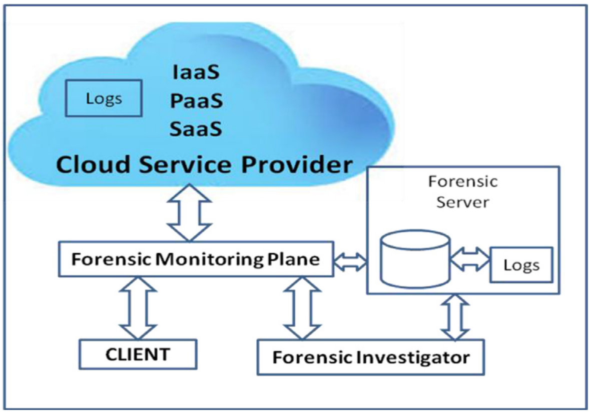

Fig. 4.1. Proposed model for cloud forensics.

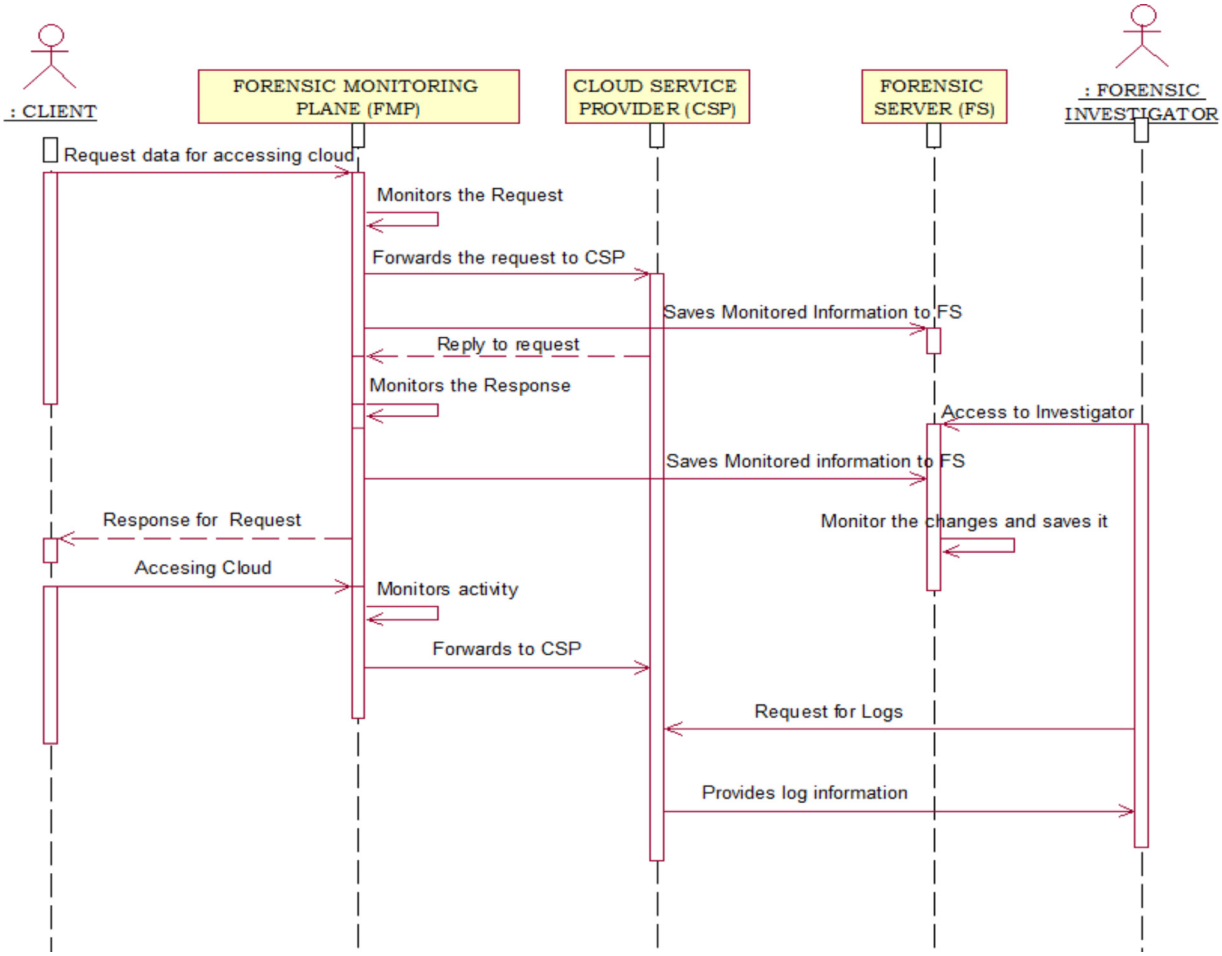

Fig. 4.2. Sequence diagram for proposed model.

forensic image process. The captured forensic images are not raw data and can be processed only through forensics tools. Network logs are also acquired from adjacent network devices (routers) and are imaged in forensics server that will give high proof for finding out the attacker.

In the case of any malicious activity, the investigator can directly login to the forensic server with their user credentials and can acquire forensic data within a time frame of the event. Meanwhile, upon suspicion, the investigator can request data from CSP and can verify it with the data obtained from the forensic server. Forensic tools are running in the forensic

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server, and it takes the forensic image of the forensic server in the case of any unexpected event since there is also a chance of a suspect logging as a forensic investigator and tamper the data. The sequence of operation in **our** proposed model is depicted in the Fig. 4.2 by a sequence diagram for better understanding.

Steps involved in the proposed model:

- The client initiates the request to the cloud service provider.
- The request and response are intercepted by FMP monitoring tool which forwards the request to the server and the response to the client, and at the same time, it forensically images the request and saves it in the forensic server.
- Forensic investigator logs into the forensic server for analyzing the evidence collected.
- Actions in the forensic server also get forensically imaged and saved in the forensic server. If the investigator suspects the CSP, he initiates the request for evidence sources from CSP and compares with one another, and hence the integrity of the collected data also gets verified.

From the proposed solution, it is evident that dependence on CSP for acquiring data is reduced. The logging challenge is also reduced by storing log files separately in a centralized manner. The new proposed forensic model will take cloud forensics to the next level.

5. Experimental setup

A virtual prototype was created for this research work in the lab with four systems which include cloud server (own cloud), forensic management plane (FMP), agent system (i.e.) compromised system in that network and master system (Original Attacker) which is shown in Fig. 5 here FMP is validated by initiating distributed denial of service (DDoS) attack and verified that all necessary information's are captured in CMP. The DDoS attack setup is assumed to be working as a Master-Handler system which includes an agent system in the network. The attacker places an HTTP DDoS attack code on the agent and commands the agents through a remote connection, for launching an attack on the victim cloud server. However the scale of the prototype is small, it does bring the essential architecture of DDoS attack. We used our attack launch code as well as DDoS tools such as sprut [25] to bring down the server.

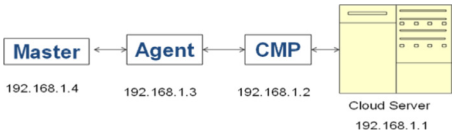
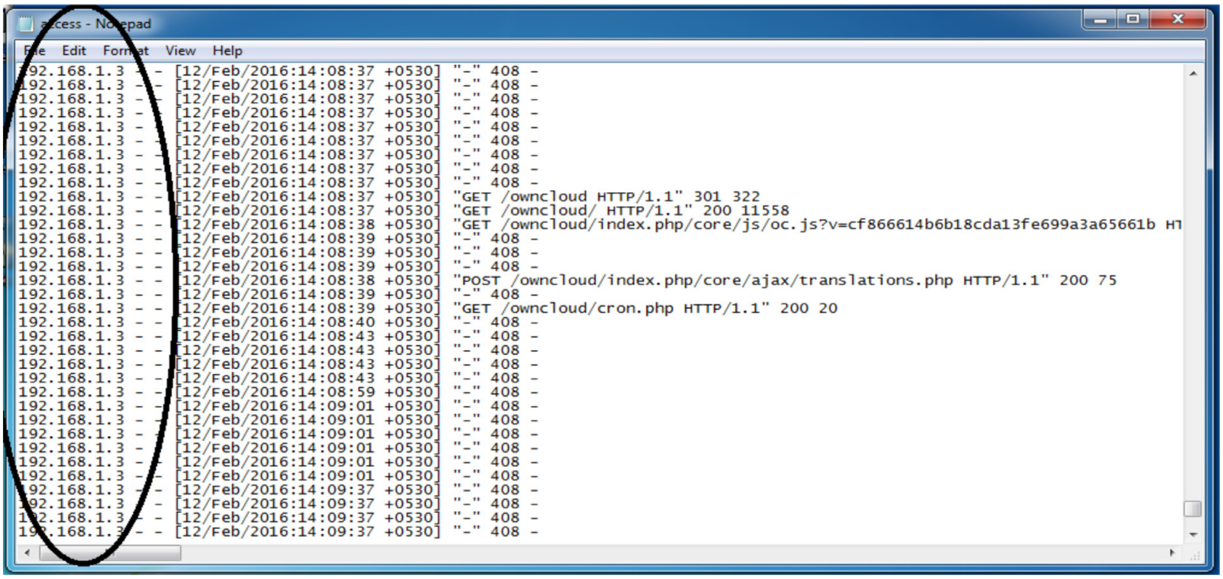


Fig. 5. Prototype setup.



```
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "GET /owncloud HTTP/1.1" 301 322
192.168.1.3 - - [12/Feb/2016:14:08:37 +0530] "GET /owncloud/ HTTP/1.1" 200 11558
192.168.1.3 - - [12/Feb/2016:14:08:38 +0530] "GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HT
192.168.1.3 - - [12/Feb/2016:14:08:39 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:39 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:39 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:38 +0530] "POST /owncloud/index.php/core/ajax/translations.php HTTP/1.1" 200 75
192.168.1.3 - - [12/Feb/2016:14:08:39 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:39 +0530] "GET /owncloud/cron.php HTTP/1.1" 200 20
192.168.1.3 - - [12/Feb/2016:14:08:40 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:43 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:08:43 +0530] "-" 408 -
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192.168.1.3 - - [12/Feb/2016:14:09:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:09:37 +0530] "-" 408 -
192.168.1.3 - - [12/Feb/2016:14:09:37 +0530] "-" 408 -
```

Fig. 6.1. Server logs- owncloud.

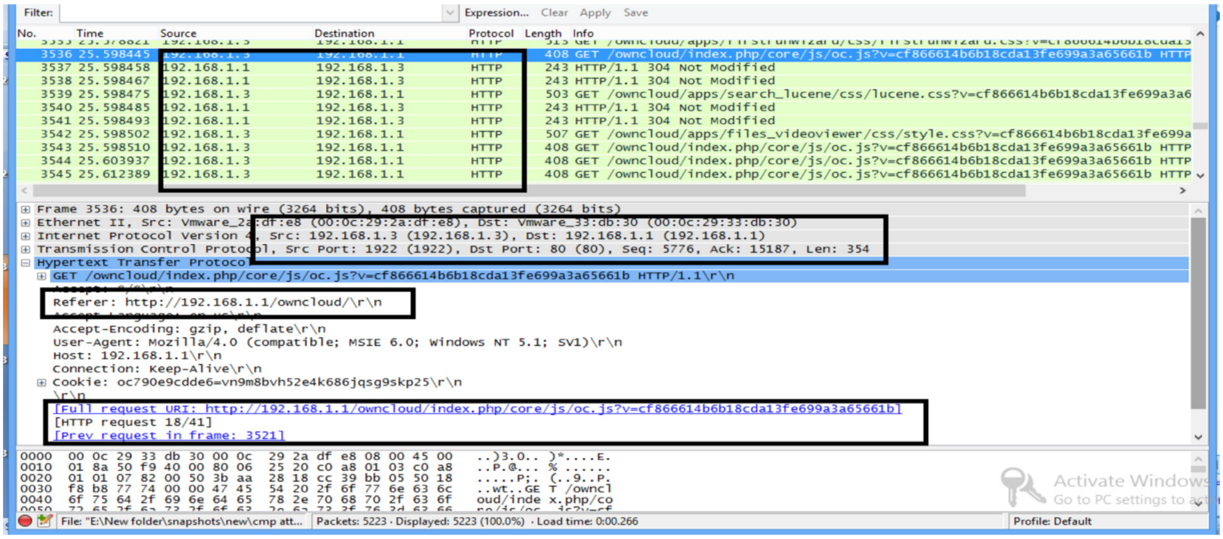
6. Results and discussions

Forensics procedure starts with tracing back from server logs in the cloud server. The attack time is the main clue for tracing the attacker, but server logs are located within the cloud service provider and the proposed model collects the entire evidence outside the cloud environment. So, a remote log analyzer is used for capturing logs from the server and packet sniffer is used to collect information in FMP. During verification of data collected in FMP, server logs identify similar IP addresses at the time of the attack. This is shown in Fig. 6.1.

Further analysis on the captured packet shows HTTP packets flooded towards the cloud server and PsExec service was executed as shown in Fig. 6.2. Tracing agent from the victim is carried out by some existing IP traceback mechanism. The focus is to traceback to the origin of the attack.

Upon successfully locating the agent system, the use of DDoS attack is identified. When the search is carried out on the basis of the time of attack in the event logs, PsExec application is found running on the agent that correlates with an attack time. This is shown in Fig.6.3. The event logs in agents do not disclose any explicit information about the master-handler.

Event logs reveal only the name of the process related to attack time and are insufficient for tracing master. Further analysis on agent using forensics toolkit analyzer (FTK) reveals the file which uses PsExec service, and it is highlighted in the Fig. 6.4.



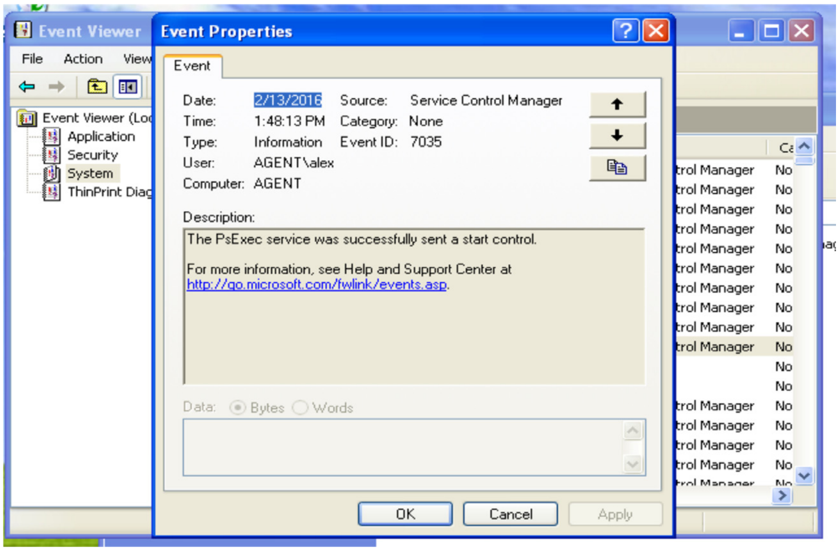
```
No.  Time      Source       Destination  Protocol Length Info
3536 25.598445 192.168.1.3  192.168.1.1  HTTP     408 GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HTTP
3537 25.598458 192.168.1.1  192.168.1.3  HTTP     243 HTTP/1.1 304 Not Modified
3538 25.598467 192.168.1.1  192.168.1.3  HTTP     243 HTTP/1.1 304 Not Modified
3539 25.598475 192.168.1.3  192.168.1.1  HTTP     503 GET /owncloud/apps/search_lucene/css/lucene.css?v=cf866614b6b18cda13fe699a3a6
3540 25.598485 192.168.1.1  192.168.1.3  HTTP     243 HTTP/1.1 304 Not Modified
3541 25.598493 192.168.1.1  192.168.1.3  HTTP     243 HTTP/1.1 304 Not Modified
3542 25.598502 192.168.1.3  192.168.1.1  HTTP     507 GET /owncloud/apps/files_videoviewer/css/style.css?v=cf866614b6b18cda13fe699a
3543 25.598510 192.168.1.3  192.168.1.1  HTTP     408 GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HTTP
3544 25.603937 192.168.1.3  192.168.1.1  HTTP     408 GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HTTP
3545 25.612389 192.168.1.3  192.168.1.1  HTTP     408 GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HTTP

⊞ Frame 3536: 408 bytes on wire (3264 bits), 408 bytes captured (3264 bits)
⊞ Ethernet II, Src: Vmware_2a:df:e8 (00:0c:29:2a:df:e8), Dst: Vmware_33:db:30 (00:0c:29:33:db:30)
⊞ Internet Protocol Version 4, Src: 192.168.1.3 (192.168.1.3), Dst: 192.168.1.1 (192.168.1.1)
⊞ Transmission Control Protocol, Src Port: 1922 (1922), Dst Port: 80 (80), Seq: 5776, Ack: 15187, Len: 354
⊟ Hypertext Transfer Protocol
  ⊞ GET /owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b HTTP/1.1\r\n
    Referer: http://192.168.1.1/owncloud/\r\n
    Accept-Encoding: gzip, deflate\r\n
    User-Agent: Mozilla/4.0 (compatible; MSIE 6.0; Windows NT 5.1; SV1)\r\n
    Host: 192.168.1.1\r\n
    Connection: Keep-Alive\r\n
  ⊞ Cookie: oc790e9cdde6=vn9m8bvh52e4k686jqsg9skp25\r\n
    \r\n
    [Full request URI: http://192.168.1.1/owncloud/index.php/core/js/oc.js?v=cf866614b6b18cda13fe699a3a65661b]
    [HTTP request 18/41]
    [Prev request in frame: 3521]

0000  00 0c 29 33 db 30 00 0c  29 2a df e8 08 00 45 00   ..)3.0.. )*....E.
0010  01 8a 50 f9 40 00 80 06  25 20 c0 a8 01 03 c0 a8   ..P.@... % ......
0020  01 01 07 82 00 50 3b aa  28 18 cc 39 bb 05 50 18   .....P;. (..9..P.
0030  f8 b8 77 74 00 00 47 45  54 20 2f 6f 77 6e 63 6c   ..wt..GE T /owncl
0040  6f 75 64 2f 69 6e 64 65  78 2e 70 68 70 2f 63 6f   oud/inde x.php/co

File: "E:\New folder\snapshots\new\cmp att...  Packets: 5223 · Displayed: 5223 (100.0%) · Load time: 0:00.266  Profile: Default
```

Fig. 6.2. FMP-data.



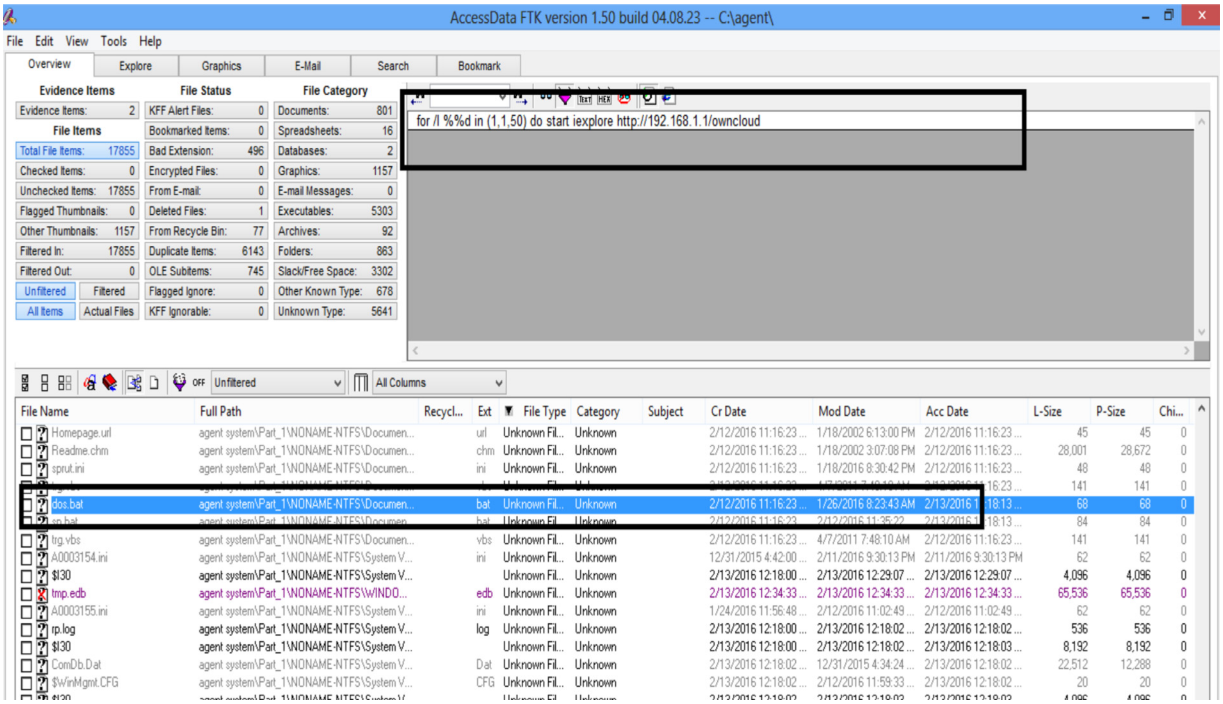
Date: 2/13/2016 Source: Service Control Manager
Time: 1:48:13 PM Category: None
Type: Information Event ID: 7035
User: AGENT\alex
Computer: AGENT

Description:
The PsExec service was successfully sent a start control.

For more information, see Help and Support Center at http://go.microsoft.com/fwlink/events.asp.

Data: ○ Bytes ○ Words

Fig. 6.3. Agent – event logs.



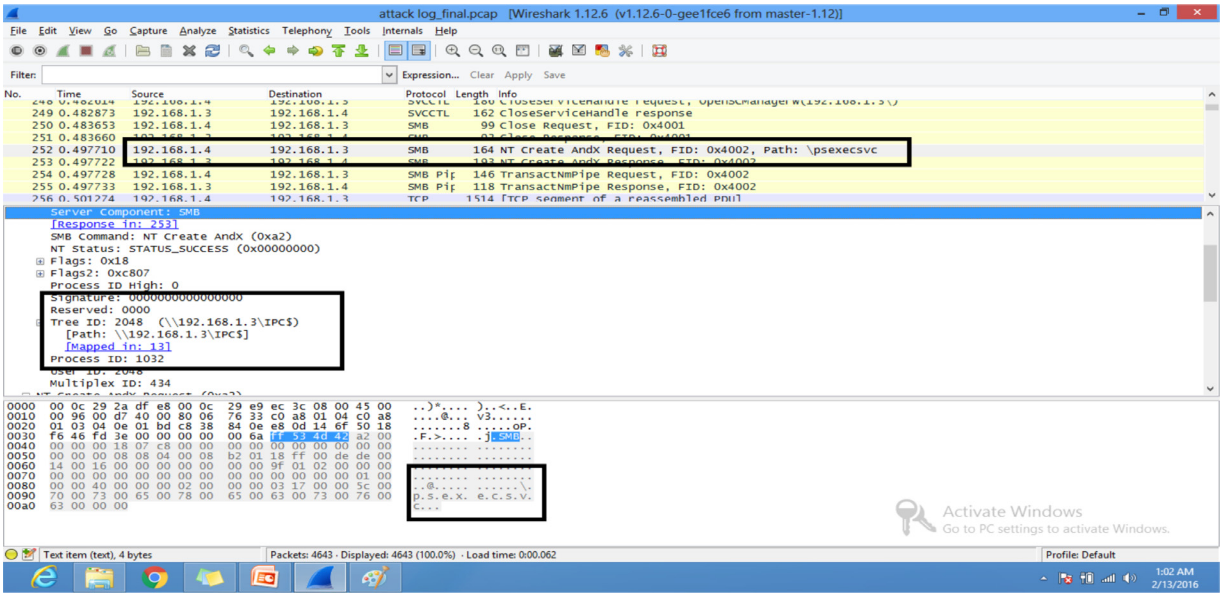
AccessData FTK version 1.50 build 04.08.23 -- C:\agent\
File Edit View Tools Help
Overview
Explore
Graphics
E-Mail
Search
Bookmark
Unfiltered
All Columns

Evidence Items		File Status		File Category	
Evidence Items:	2	KFF Alert Files:	0	Documents:	801
File Items		Bookmarked Items:	0	Spreadsheets:	16
Total File Items:	17855	Bad Extension:	496	Databases:	2
Checked Items:	0	Encrypted Files:	0	Graphics:	1157
Unchecked Items:	17855	From E-mail:	0	E-mail Messages:	0
Flagged Thumbnails:	0	Deleted Files:	1	Executables:	5303
Other Thumbnails:	1157	From Recycle Bin:	77	Archives:	92
Filtered In:	17855	Duplicate Items:	6143	Folders:	863
Filtered Out:	0	OLE Subitems:	745	Slack/Free Space:	3302
Unfiltered	Filtered	Flagged Ignore:	0	Other Known Type:	678
All Items	Actual Files	KFF Ignorable:	0	Unknown Type:	5641

```
for /l %%d in (1,1,50) do start iexplore http://192.168.1.1/owncloud
```

File Name	Full Path	Recycl...	Ext	File Type	Category	Subject	Cr Date	Mod Date	Acc Date	L-Size	P-Size	Chi...
Homepage.url	agent system\Part_1\NONAME-NTFS\Documen...		url	Unknown Fil...	Unknown		2/12/2016 11:16:23 ...	1/18/2002 6:13:00 PM	2/12/2016 11:16:23 ...	45	45	0
Readme.chm	agent system\Part_1\NONAME-NTFS\Documen...		chm	Unknown Fil...	Unknown		2/12/2016 11:16:23 ...	1/18/2002 3:07:08 PM	2/12/2016 11:16:23 ...	28,001	28,672	0
sprut.ini	agent system\Part_1\NONAME-NTFS\Documen...		ini	Unknown Fil...	Unknown		2/12/2016 11:16:23 ...	1/18/2016 8:30:42 PM	2/12/2016 11:16:23 ...	48	48	0
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	...16:23 ...	141	141	0
dos.bat	agent system\Part_1\NONAME-NTFS\Documen...		bat	Unknown Fil...	Unknown		2/12/2016 11:16:23 ...	1/26/2016 8:23:43 AM	2/13/2016 1 :18:13 ...	68	68	0
sp.bat	agent system\Part_1\NONAME-NTFS\Documen...		bat	Unknown Fil...	Unknown		2/12/2016 11:16:23	2/12/2016 11:35:22	2/13/2016 1 :18:13 ...	84	84	0
trg.vbs	agent system\Part_1\NONAME-NTFS\Documen...		vbs	Unknown Fil...	Unknown		2/12/2016 11:16:23 ...	4/7/2011 7:48:10 AM	2/12/2016 11:16:23 ...	141	141	0
A0003154.ini	agent system\Part_1\NONAME-NTFS\System V...		ini	Unknown Fil...	Unknown		12/31/2015 4:42:00 ...	2/11/2016 9:30:13 PM	2/11/2016 9:30:13 PM	62	62	0
$I30	agent system\Part_1\NONAME-NTFS\System V...			Unknown Fil...	Unknown		2/13/2016 12:18:00 ...	2/13/2016 12:29:07 ...	2/13/2016 12:29:07 ...	4,096	4,096	0
tmp.edb	agent system\Part_1\NONAME-NTFS\WINDO...		edb	Unknown Fil...	Unknown		2/13/2016 12:34:33 ...	2/13/2016 12:34:33 ...	2/13/2016 12:34:33 ...	65,536	65,536	0
A0003155.ini	agent system\Part_1\NONAME-NTFS\System V...		ini	Unknown Fil...	Unknown		1/24/2016 11:56:48 ...	2/12/2016 11:02:49 ...	2/12/2016 11:02:49 ...	62	62	0
rp.log	agent system\Part_1\NONAME-NTFS\System V...		log	Unknown Fil...	Unknown		2/13/2016 12:18:00 ...	2/13/2016 12:18:02 ...	2/13/2016 12:18:02 ...	536	536	0
$I30	agent system\Part_1\NONAME-NTFS\System V...			Unknown Fil...	Unknown		2/13/2016 12:18:00 ...	2/13/2016 12:18:02 ...	2/13/2016 12:18:03 ...	8,192	8,192	0
ComDb.Dat	agent system\Part_1\NONAME-NTFS\System V...		Dat	Unknown Fil...	Unknown		2/13/2016 12:18:02 ...	12/31/2015 4:34:24 ...	2/13/2016 12:18:02 ...	22,512	12,288	0
$WinMgmt.CFG	agent system\Part_1\NONAME-NTFS\System V...		CFG	Unknown Fil...	Unknown		2/13/2016 12:18:02 ...	2/12/2016 11:59:33 ...	2/13/2016 12:18:02 ...	20	20	0
$I30	agent system\Part_1\NONAME-NTFS\System V...			Unknown Fil...	Unknown		2/13/2016 12:18:02	2/13/2016 12:18:03	2/13/2016 12:18:03	4,096	4,096	0

Fig. 6.4. Agent FTK.



attack log_final.pcap [Wireshark 1.12.6 (v1.12.6-0-gee1fce6 from master-1.12)]
File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Filter:
Expression...
Clear
Apply
Save
Activate Windows
Go to PC settings to activate Windows.
Profile: Default
1:02 AM
2/13/2016

```
No.     Time        Source          Destination     Protocol  Length  Info
    248 0.482614    192.168.1.4     192.168.1.3     SVCCTL     180 CloseServiceHandle request, OpenSCManagerW(192.168.1.3\)
    249 0.482873    192.168.1.3     192.168.1.4     SVCCTL     162 CloseServiceHandle response
    250 0.483653    192.168.1.4     192.168.1.3     SMB         99 Close Request, FID: 0x4001
    251 0.483660    192.168.1.3     192.168.1.4     SMB         93 Close Response, FID: 0x4001
    252 0.497710    192.168.1.4     192.168.1.3     SMB        164 NT Create AndX Request, FID: 0x4002, Path: \psexecsvc
    253 0.497722    192.168.1.3     192.168.1.4     SMB        193 NT Create AndX Response, FID: 0x4002
    254 0.497728    192.168.1.4     192.168.1.3     SMB Pip    146 TransactNmPipe Request, FID: 0x4002
    255 0.497733    192.168.1.3     192.168.1.4     SMB Pip    118 TransactNmPipe Response, FID: 0x4002
    256 0.501274    192.168.1.4     192.168.1.3     TCP       1514 [TCP segment of a reassembled PDU]
```

```
    Server Component: SMB
    [Response in: 253]
    SMB Command: NT Create AndX (0xa2)
    NT Status: STATUS_SUCCESS (0x00000000)
  ⊞ Flags: 0x18
  ⊞ Flags2: 0xc807
    Process ID High: 0
    Signature: 0000000000000000
    Reserved: 0000
  ⊟ Tree ID: 2048  (\\192.168.1.3\IPC$)
      [Path: \\192.168.1.3\IPC$]
      [Mapped in: 13]
    Process ID: 1032
    User ID: 2048
    Multiplex ID: 434
⊟ NT Create AndX Request (0xa2)
```

```
0000  00 0c 29 2a df e8 00 0c  29 e9 ec 3c 08 00 45 00   ..)*.... )..<..E.
0010  00 96 00 d7 40 00 80 06  76 33 c0 a8 01 04 c0 a8   ....@... v3......
0020  01 03 04 0e 01 bd c8 38  84 0e e8 0d 14 6f 50 18   .......8 .....oP.
0030  f6 46 fd 3e 00 00 00 00  00 6a ff 53 4d 42 a2 00   .F.>.... .j.SMB..
0040  00 00 00 18 07 c8 00 00  00 00 00 00 00 00 00 00   ........ ........
0050  00 00 00 08 08 04 00 08  b2 01 18 ff 00 de de 00   ........ ........
0060  14 00 16 00 00 00 00 00  00 00 9f 01 02 00 00 00   ........ ........
0070  00 00 00 00 00 00 00 00  00 00 00 00 00 00 01 00   ........ ........
0080  00 00 40 00 00 00 02 00  00 00 03 17 00 00 5c 00   ..@..... ......\.
0090  70 00 73 00 65 00 78 00  65 00 63 00 73 00 76 00   p.s.e.x. e.c.s.v.
00a0  63 00 00 00                                        c...
```

```
Text item (text), 4 bytes    Packets: 4643 · Displayed: 4643 (100.0%) · Load time: 0:00.062
```

Fig. 6.5. FMP – master to agent (attack initiation).

The earlier investigation indicates that PsExec service was started during the attack time as shown in Fig. 6.3, but an in-depth analysis on agent system using forensic tool kit (FTK) confirms that agent system is used for attacking the server and is controlled remotely as shown in Fig. 6.4.

Further analysis of network log collected in FMP indicates that PsExec service was started remotely by remote user as highlighted in the Fig. 6.5. Analysis on CMP data clearly indicates that the source of the remote process is not the agent system but the attack code is launched remotely from the agent. Even though the investigation has collected enough evidence against the agent and master of the attack, it reveals little information about the master system. On further analysis of FMP network logs, the master placing attack codes in the agent system can be identified as depicted in Fig. 6.6.

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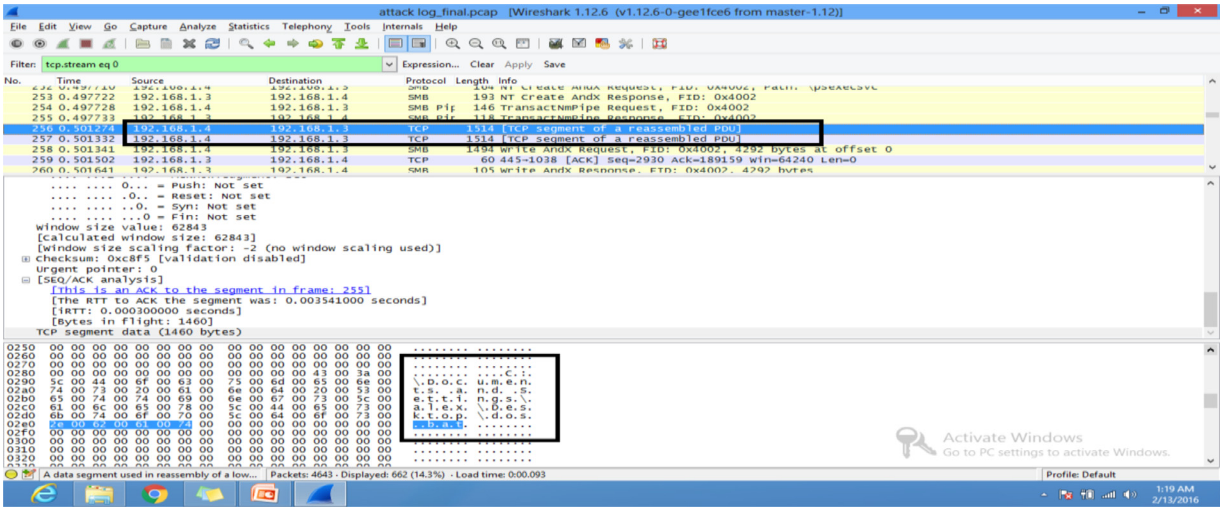


attack log_final.pcap [Wireshark 1.12.6 (v1.12.6-0-gee1fce6 from master-1.12)]

Filter: tcp.stream eq 0

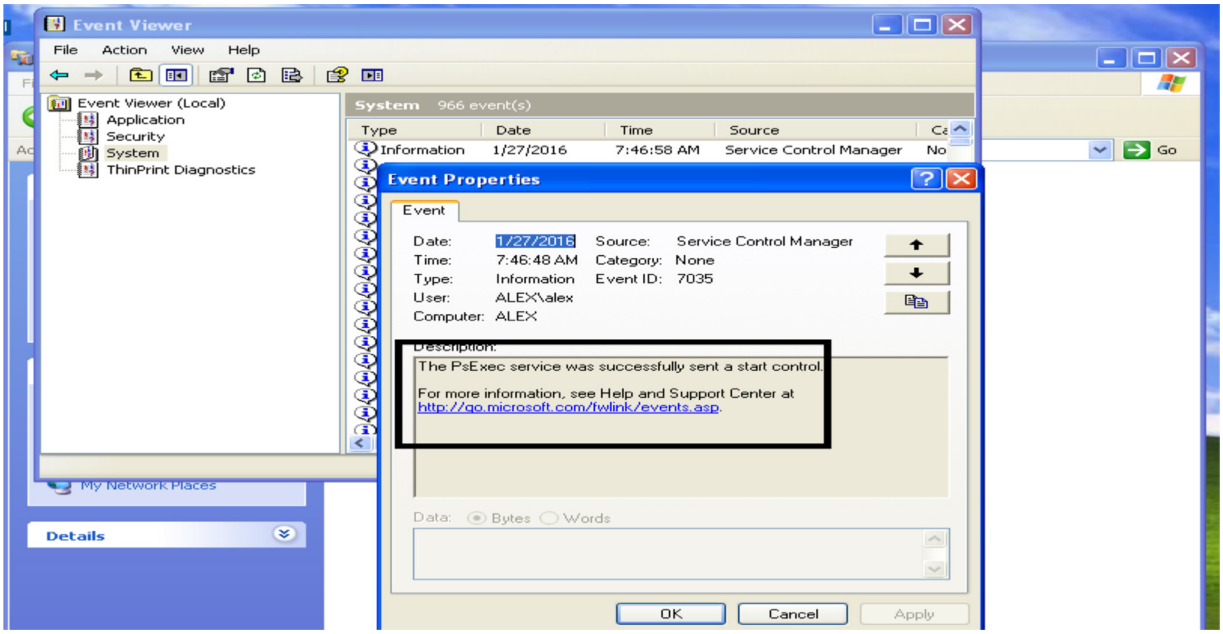
```
No.  Time      Source        Destination   Protocol Length Info
252 0.497710  192.168.1.4   192.168.1.3   SMB       104 NT Create AndX Request, FID: 0x4002, Path: \psexecsvc
253 0.497722  192.168.1.3   192.168.1.4   SMB       193 NT Create AndX Response, FID: 0x4002
254 0.497728  192.168.1.4   192.168.1.3   SMB Pip   146 TransactNmPipe Request, FID: 0x4002
255 0.497733  192.168.1.3   192.168.1.4   SMB Pip   118 TransactNmPipe Response, FID: 0x4002
256 0.501274  192.168.1.4   192.168.1.3   TCP      1514 [TCP segment of a reassembled PDU]
257 0.501332  192.168.1.4   192.168.1.3   TCP      1514 [TCP segment of a reassembled PDU]
258 0.501341  192.168.1.4   192.168.1.3   SMB      1494 Write AndX Request, FID: 0x4002, 4292 bytes at offset 0
259 0.501502  192.168.1.3   192.168.1.4   TCP        60 445→1038 [ACK] Seq=2930 Ack=189159 Win=64240 Len=0
260 0.501641  192.168.1.3   192.168.1.4   SMB       105 Write AndX Response, FID: 0x4002, 4292 bytes
```

```
        .... .... 0... = Push: Not set
        .... .... .0.. = Reset: Not set
        .... .... ..0. = Syn: Not set
        .... .... ...0 = Fin: Not set
     Window size value: 62843
     [Calculated window size: 62843]
     [Window size scaling factor: -2 (no window scaling used)]
  ⊞ Checksum: 0xc8f5 [validation disabled]
     Urgent pointer: 0
  ⊟ [SEQ/ACK analysis]
       [This is an ACK to the segment in frame: 255]
       [The RTT to ACK the segment was: 0.003541000 seconds]
       [iRTT: 0.000300000 seconds]
       [Bytes in flight: 1460]
     TCP segment data (1460 bytes)
```

```
0250  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0260  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0270  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0280  00 00 00 00 00 00 00 00  00 00 00 00 43 00 3a 00   ........ ....C.:.
0290  5c 00 44 00 6f 00 63 00  75 00 6d 00 65 00 6e 00   \.D.o.c. u.m.e.n.
02a0  74 00 73 00 20 00 61 00  6e 00 64 00 20 00 53 00   t.s. .a. n.d. .S.
02b0  65 00 74 00 74 00 69 00  6e 00 67 00 73 00 5c 00   e.t.t.i. n.g.s.\.
02c0  61 00 6c 00 65 00 78 00  5c 00 44 00 65 00 73 00   a.l.e.x. \.D.e.s.
02d0  6b 00 74 00 6f 00 70 00  5c 00 64 00 6f 00 73 00   k.t.o.p. \.d.o.s.
02e0  2e 00 62 00 61 00 74 00  00 00 00 00 00 00 00 00   ..b.a.t. ........
02f0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0300  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0310  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0320  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
```

A data segment used in reassembly of a low... Packets: 4643 · Displayed: 662 (14.3%) · Load time: 0:00.093 Profile: Default

Fig. 6.6. Master placing attack (dos.bat) file.



Event Viewer

System 966 event(s)

Type	Date	Time	Source	Ca
Information	1/27/2016	7:46:58 AM	Service Control Manager	No

Event Properties

Date: 1/27/2016 Source: Service Control Manager
Time: 7:46:48 AM Category: None
Type: Information Event ID: 7035
User: ALEX\alex
Computer: ALEX

Description:
The PsExec service was successfully sent a start control.

For more information, see Help and Support Center at http://go.microsoft.com/fwlink/events.asp.

Data: ● Bytes ○ Words

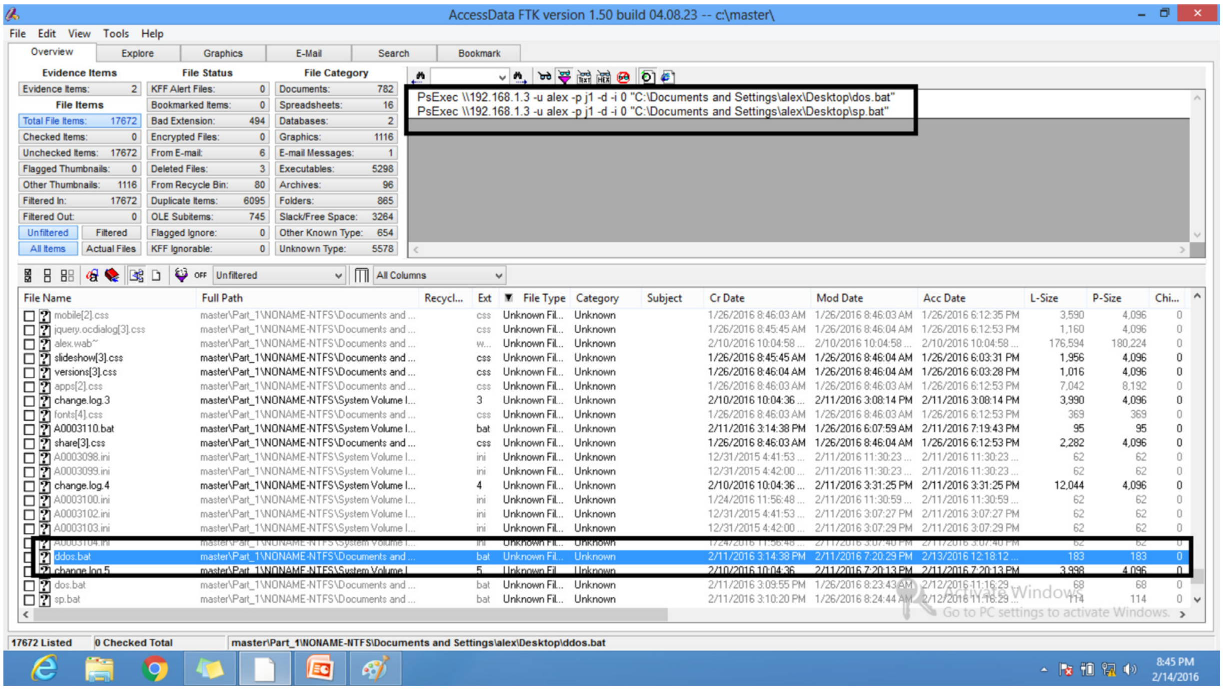
Fig. 6.7. Event logs – master.

For creating additional evidence against the master, the investigator moves into event logs in the master as done in the agent system and it indicates that PsExec service is started which correlates with attack scenario as shown in Fig. 6.7.

Further analysis on the master system using FTK analyzer reveals the attack code used for initializing the agent code that attacks the server. This creates additional evidence against the master, leading to the investigator's conclusion that the corresponding master is the original attacker. This is depicted in Fig. 6.8.

7. Conclusions and future work

The need for cloud forensics is on the rise, because of its rapid growth in cloud computing and due to the possibility of cloud-related crime occurring in the digital world. There are many challenges in cloud forensics and only a few researchers have addressed these challenges. In this paper, the challenges faced in cloud forensics and corresponding solutions addressed by the researchers have been highlighted in depth. A new model for mitigating the challenges in cloud forensics has been proposed and validated with DDoS attack to check whether the proposed FMP collects all necessary information related to fraudulent activities required for forensics analysis. In future, the entire attack scenario will be modeled inside the cloud



Evidence Items		File Status		File Category	
Evidence Items:	2	KFF Alert Files:	0	Documents:	782
File Items		Bookmarked Items:	0	Spreadsheets:	16
Total File Items:	17672	Bad Extension:	494	Databases:	2
Checked Items:	0	Encrypted Files:	0	Graphics:	1116
Unchecked Items:	17672	From E-mail:	6	E-mail Messages:	1
Flagged Thumbnails:	0	Deleted Files:	3	Executables:	5298
Other Thumbnails:	1116	From Recycle Bin:	80	Archives:	96
Filtered In:	17672	Duplicate Items:	6095	Folders:	865
Filtered Out:	0	OLE Subitems:	745	Slack/Free Space:	3264
Unfiltered	Filtered	Flagged Ignore:	0	Other Known Type:	654
All Items	Actual Files	KFF Ignorable:	0	Unknown Type:	5578

```
PsExec \\192.168.1.3 -u alex -p j1 -d -i 0 "C:\Documents and Settings\alex\Desktop\dos.bat"
PsExec \\192.168.1.3 -u alex -p j1 -d -i 0 "C:\Documents and Settings\alex\Desktop\sp.bat"
```

File Name	Full Path	Recycl...	Ext	File Type	Category	Subject	Cr Date	Mod Date	Acc Date	L-Size	P-Size	Chi...
□ mobile[2].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:46:03 AM	1/26/2016 8:46:03 AM	1/26/2016 6:12:35 PM	3,590	4,096	0
□ jquery.ocdialog[3].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:45:45 AM	1/26/2016 8:46:04 AM	1/26/2016 6:12:53 PM	1,160	4,096	0
□ alex.wab~	master\Part_1\NONAME-NTFS\Documents and ...		w...	Unknown Fil...	Unknown		2/10/2016 10:04:58 ...	2/10/2016 10:04:58 ...	2/10/2016 10:04:58 ...	176,594	180,224	0
□ slideshow[3].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:45:45 AM	1/26/2016 8:46:04 AM	1/26/2016 6:03:31 PM	1,956	4,096	0
□ versions[3].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:46:04 AM	1/26/2016 8:46:04 AM	1/26/2016 6:03:28 PM	1,016	4,096	0
□ apps[2].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:46:03 AM	1/26/2016 8:46:03 AM	1/26/2016 6:12:53 PM	7,042	8,192	0
□ change.log.3	master\Part_1\NONAME-NTFS\System Volume I...		3	Unknown Fil...	Unknown		2/10/2016 10:04:36 ...	2/11/2016 3:08:14 PM	2/11/2016 3:08:14 PM	3,990	4,096	0
□ fonts[4].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:46:03 AM	1/26/2016 8:46:03 AM	1/26/2016 6:12:53 PM	369	369	0
□ A0003110.bat	master\Part_1\NONAME-NTFS\System Volume I...		bat	Unknown Fil...	Unknown		2/11/2016 3:14:38 PM	1/26/2016 6:07:59 AM	2/11/2016 7:19:43 PM	95	95	0
□ share[3].css	master\Part_1\NONAME-NTFS\Documents and ...		css	Unknown Fil...	Unknown		1/26/2016 8:46:03 AM	1/26/2016 8:46:04 AM	1/26/2016 6:12:53 PM	2,282	4,096	0
□ A0003098.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		12/31/2015 4:41:53 ...	2/11/2016 11:30:23 ...	2/11/2016 11:30:23 ...	62	62	0
□ A0003099.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		12/31/2015 4:42:00 ...	2/11/2016 11:30:23 ...	2/11/2016 11:30:23 ...	62	62	0
□ change.log.4	master\Part_1\NONAME-NTFS\System Volume I...		4	Unknown Fil...	Unknown		2/10/2016 10:04:36 ...	2/11/2016 3:31:25 PM	2/11/2016 3:31:25 PM	12,044	4,096	0
□ A0003100.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		1/24/2016 11:56:48 ...	2/11/2016 11:30:59 ...	2/11/2016 11:30:59 ...	62	62	0
□ A0003102.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		12/31/2015 4:41:53 ...	2/11/2016 3:07:27 PM	2/11/2016 3:07:27 PM	62	62	0
□ A0003103.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		12/31/2015 4:42:00 ...	2/11/2016 3:07:29 PM	2/11/2016 3:07:29 PM	62	62	0
□ A0003104.ini	master\Part_1\NONAME-NTFS\System Volume I...		ini	Unknown Fil...	Unknown		1/24/2016 11:56:48 ...	2/11/2016 3:07:40 PM	2/11/2016 3:07:40 PM	62	62	0
□ ddos.bat	master\Part_1\NONAME-NTFS\Documents and ...		bat	Unknown Fil...	Unknown		2/11/2016 3:14:38 PM	2/11/2016 7:20:29 PM	2/13/2016 12:18:12 ...	183	183	0
□ change.log.5	master\Part_1\NONAME-NTFS\System Volume I		5	Unknown Fil	Unknown		2/10/2016 10:04:36	2/11/2016 7:20:13 PM	2/11/2016 7:20:13 PM	3,998	4,096	0
□ dos.bat	master\Part_1\NONAME-NTFS\Documents and ...		bat	Unknown Fil...	Unknown		2/11/2016 3:09:55 PM	1/26/2016 8:23:43 AM	2/12/2016 11:16:29 ...	68	68	0
□ sp.bat	master\Part_1\NONAME-NTFS\Documents and ...		bat	Unknown Fil...	Unknown		2/11/2016 3:10:20 PM	1/26/2016 8:24:44 AM	2/12/2016 11:16:29 ...	114	114	0

17672 Listed | 0 Checked Total | master\Part_1\NONAME-NTFS\Documents and Settings\alex\Desktop\ddos.bat

Fig. 6.8. FTK analysis - master.

environment for checking whether the proposed FMP collects all necessary information related to fraudulent activities. On completion, other modules in the proposed solution will be implemented.

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