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Forensic Investigation of Cooperative Storage Cloud Service: Symform as a Case Study

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Abstract

Researchers envisioned the Storage as a Service (StaaS) as an effective solution to the distributed management of digital data, since it provides an inexpensive and reliable online storage which is accessible by different types of computer devices (e.g., mobile and desktop). However, the proliferation of cloud storage services has fuelled concerns over privacy and security (e.g., dissemination of malware and unauthorised access of private information). Together with the growing of StaaS proposals, cloud storage is attracting the attention of research, although cooperative storage cloud forensic is relatively under-explored as this is a fairly new concept. Using Symform as a case study, we seek to determine the data remnants from the use of cooperative cloud storage services. In particular, we consider both mobile devices and personal computers running various popular operating systems, namely Windows 8.1, Mac OS X Mavericks 10.9.5, Ubuntu 14.04 LTS, iOS 7.1.2, and Android KitKat 4.4. Potential artefacts recovered during the research include data relating to the installation and uninstallation of the cloud applications, log-in to and log-off from symform account using the client application, file synchronisation (download, upload, and delete), as well as their timestamp information. This research contributes to an in-depth understanding of the types of terrestrial artefacts that are likely to remain after the use of cooperative storage cloud on client devices.

Keywords: Cloud Forensics, Computer Forensics, Mobile Forensics, Symform Analysis.

1. Introduction

Cloud computing is, arguably, one of the most discussed computing paradigms in recent years, due to its popularity among individual consumers and organisations. Gartner [1] forecasted that the cloud computing market will hit US$250 billion by 2017 as cloud adoption increases in organisations. International Data Corporation (IDC) [2] also published a similar forecast, which indicated that the worth of the cloud computing market will exceed US$107 billion and drive 17% of the IT product spending by 2017.

Despite the promising economical and technological opportunities, cloud storage services are also being exploited by criminals, both traditional and cyber ones [3], in several ways such as information theft [4, 5, 6, 7] or distributing copyright or illegal materials. Cloud servers have also been exploited as an avenue for conducting denial of service attacks [8], cracking passwords [9], and hiding criminal tracks [5].

Since the introduction of cloud computing, scholars have pointed out the challenges in conducting forensic investigations involving the use of cloud storage services. These challenges mostly come from the lack of physical access to digital artefacts over the servers spanning across multiple jurisdictional areas, as well as integrity of data artefacts (e.g., log files) provided by the Cloud Service Providers (CSPs) [10, 11, 12, 13, 14, 15, 16, 17]. Even if the evidence could be identified, it could be illegal to access the raw log data that contains records of multiple users in a multi-tenancy cloud environment [18]. The wide range of mobile devices [19] and the use of encryption by CSPs or individuals [12] further complicate cloud forensic investigations.

To ensure timely and cost-effective responses to investigating cloud-related incidents, it is imperative that forensic examiners are cognisant about different types of cloud products (or have access to such information), as well as the potential artefacts detectable on each platform [20, 21, 22, 14, 23]. Depending on the cloud storage solution in use, evidence (e.g., logs) of cloud usage could be recovered from the client devices [21, 22, 24, 25, 26, 27, 28]. Hence, we seek to identify potential terrestrial artefacts that may remain after the use of Symform cooperative storage cloud [29].

1.1. Background

A cooperative storage cloud is a fully decentralized storage model that aggregates multiple cooperating nodes (e.g., game consoles, laptop, and personal computers) in the cloud environment [30]. By eliminating the need

for storage servers, it offers a low cost, highly reliable, and secure cloud storage system. Symform (Symbiotic Storage Platform) claims to be the first cooperative storage cloud provider and reportedly has active users in 138 countries [31]. In 2014, Symform received the *Best Cloud Storage Solution* award in the 4th Annual Cloud Computing World Series [32]. The free service allows users to store up to 10GB of storage. Users may acquire additional space (up to 200GB) by donating a portion of unused space on their local hard drive to Symform network for other users to store data. The users, in return, receive 50% cloud storage space of the total hard drive space contributed. Alternatively, users are able to purchase additional space as low as $10.00/month for 100GB storage [29].

To ensure secure storage of users' data across its network of contributed devices, Symform encrypts each sync/backup folder using 256-bit AES encryption and breaks down each file into 64MB small data blocks. Then, the blocks are shredded further into sixty-four 1MB encrypted fragments before geographically distributing those fragments in parallel across 96 different nodes in the Symform network [33]. The index and encryption key of the transmitted data reside on the file owner's computer. When a file is uploaded, Symform's *Cloud Control*, the cloud management service hosted by Amazon Web Services (EC2), will constantly monitor all the peer devices containing fragments of the file data blocks. In cases when a peer device is down or at risk of failure, the system will automatically regenerate the fragments at risk and distribute them to another contributing device in Symform network, thereby increasing reliability and integrity of the data storage.

Similar to other cloud storage services, Symform service can be accessed using a web browser (but limited to the downloading, viewing and deleting the files) or a client application available for devices running Microsoft Windows, Apple Mac OS X, Linux, Apple iOS, Android, and Blackberry. Unlike most cloud storage services, Symform allows users to selectively backup any folder across different devices. Symform users are required to install the client application to setup and enable file synchronisation. The user interface for the Linux and Mac (in alternative) client application is a web-based Graphical User Interface (GUI) known as the Remote Device Manager (RDM), which is accessible through `'localhost:59234'` by default. The default Symform backup folders created by the OS are Music, Pictures, Desktop, and Documents folders; which can be modified by the users. Notice that Symform does not provide the ability for file sharing.

1.2. Related work

Since the early 2010's, a number of scholars have highlighted operational and legal challenges and various research opportunities associated with cloud forensic investigations [34, 35, 36, 37, 38, 39, 13, 10]. Recently, some researchers published a number of technical solutions to mitigate the identified challenges [40, 41, 42, 43, 23], particularly those associated with the remote collection of data artefacts from a decentralised cloud infrastructure. Moreover, some other researchers also explored the potential of collecting evidence from client devices [11, 21, 22, 24, 20, 44, 45, 25, 26, 27, 28, 17] and servers [46, 47, 17]. Other research efforts include:

- Evaluation of the effectiveness of commercial forensic tools (e.g., Guidance EnCase, the Forensics Tool Kit (FTK), Memoryze, and AWS Export) in acquiring evidence remotely from the Amazon EC2 servers [48].

- Determining whether the integrity (e.g., any change in MD5, SHA1, and timestamps) of the synced files acquired from popular cloud storage providers, such as Dropbox, Google Drive, Microsoft SkyDrive [14] and iCloud [45], are affected in the forensic collection.

- Proposal of frameworks, guidelines and methodologies with the aims of providing a systematic approach for forensic collection of cloud artefacts from servers and/or client devices. Martini and Choo [46] were the first to propose cloud forensic framework, which was used to investigate ownCloud [47], Amazon EC2 [44], VMWare [23], and XtreemFS [49]. Subsequently, Quick and Choo [21, 24] and Quick et al. [17] extended the four-stage framework and validated using SkyDrive, Dropbox, Google Drive and ownCloud [17]. Chung et al. [11] proposed a cloud investigation guideline and utilised it to investigate Amazon S3, Google Docs, and Evernote on Windows, Mac OS, iOS, and Android devices. Farina et al. [25] investigated the artefacts left by Bit Torrent Sync and outlined an investigative framework for the remote collection of evidence from a decentralised file synchronisation network [50]. Scanlon et al. [51] further extended the work of Farina et al. [25] and designed a methodology for the network investigation of Bit Torrent Sync.

Due to the recency of cooperative storage cloud services, this is the first forensic research undertaken to identify artefacts of forensic interest that may remain after the use of such services on the client's device.

1.3. Contribution

Similar to the approaches of Quick and Choo [21, 22, 24], we attempt to answer the following questions in this research:

1. Does the act of file download or file upload using Symform cooperative storage cloud alter the file contents and timestamps of the original files?

2. What artefacts can be found on a computer hard drive and memory after a user has used the Symform client application and web application? where are their locations on Windows 8.1, Ubuntu 14.04 LTS, and Mac OS X Mavericks 10.9.5?

3. What data remains on an Apple iPhone 4 and an HTC One X after a user has used the Symform client apps? where are their locations on iOS Version 7.1.2, and Android KitKat 4.4?

4. What data can be seen in network traffic?

Findings from this research will contribute to the forensic community's understanding of the types of terrestrial artefacts that are likely to remain after the use of cooperative storage cloud on devices (e.g., personal computers and mobile devices) running different operating systems.

1.4. Outline

The structure of this paper is as follows. Section 2 outlines the research methodology. Section 3 details the evidence collection phase, which will answer the first research question. Sections 4 and 5 discuss the findings from the technical experiments involving the personal computers and mobile devices. These sections will answer the second and third research questions. Section 6 explains the network artefacts, which will answer the final research question of this research study. Finally, in Section 7, we conclude the paper and outline potential future research areas.

2. Research Methodology

This section provides an overview of the cloud investigation framework used to guide the investigations in this paper as well as the experimental setup.

2.1. Cloud investigation framework

It is essential that (digital) forensic investigators or practitioners adhere to generally accepted forensic principles, standards, guidelines, procedures and best practices when undertaking digital forensic investigations [52, 53]. In particular, Kent et al. [54] (p.5) define the forensic process as follows:

> *"An individual performing forensic activities needs to understand forensic principles and practices, and follow the correct procedures for each activity, regardless of which group he or she is a member."*

As an example, Mckemmish [55] explained that digital forensic investigations should be based on four principles, namely minimal of the original, account for any changes, comply with the rules of evidence, and not to exceed knowledge. Moreover, the National Institute of Standards and Technology (NIST) prescribed that a digital forensics framework should contain the necessary components, namely collection, examination, analysis, and reporting [54].

In this research, we adopt the cloud investigative framework proposed by Martini and Choo [46] as shown in Figure 1. While the framework shares several similarities with the frameworks of McKemmish [55] and NIST [54], it differs in a number of ways. The primary difference being that of the third phase, which emphasises one or more simultaneous iteration(s) of the framework with evidence source identification and preservation via the associated devices. These comprise remote servers, peer nodes (in P2P storage cloud investigation), and other connected devices typically identifiable from a client device.

In the following, we briefly explain each of the four investigation phases in the context of our research.

1. *Evidence source identification and preservation.* In the first phase, we identify the physical hardware of interest, which contained the virtual disk files (VMDK) and virtual memory files (VMEM) in each VM folder. The mobile devices used in this research were an HTC One X running Android KitKat 4.4 and an Apple iPhone 4 running iOS Version 7.1.2. We created and verified a forensic copy of each VMDK and VMEM file in E01 container and raw image file (dd) formats respectively. For the mobile devices, we acquired a bit-for-bit image of the internal storage and we converted it to the E01 container format. Then, we calculated

an MD5 hash value for each original file and subsequently we verified each copy.

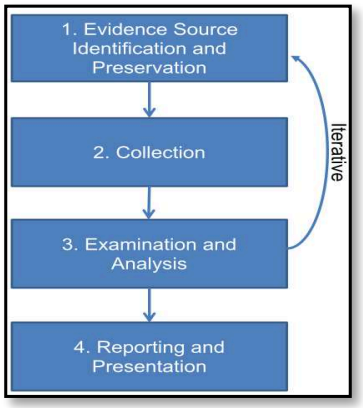


Figure 1: Cloud forensics framework of Martini and Choo [46].

2. *Collection.* In this phase, we collected files containing the details needed for analysis and keyword searching in the forensic copies. Similar to the earlier evidence source identification and preservation phase, we calculated the MD5 and SHA1 hash values of each original file and subsequently verified each collected or exported file. Further details of this phase are explained in Section 3.

3. *Analysis.* This phase is concerned with the examination and analysis of data at rest, in motion, or in execution. We undertook data parsing, carving, and keyword search for Symform artefacts located in the forensic copies of volatile and non-volatile data captures. We considered both indexed and non-indexed, as well as Unicode and non-Unicode string searches (in Hex editor) as part of our keyword search. The following search terms were identified after examining the file names observed and the text from within the Enron data files:

   - `symform.com`, symform.
   - `3111.zip`, `3111.pdf`, `3111.docx`, `3111.jpg`, `3111.rft`, `3111.txt`, `13100.zip`, `13100.pdf`, `13100.docx`, `13100.jpg`, `13100.rft`, `13100.txt`, Enron, Pensive Parakeet.

- the username and password created for this research.

4. *Reporting and presentation.* This phase involves legal presentation of the collected evidential data in a court of law.

2.2. Experimental setup

For our analysis, we created a total of 33 VMs each one representing different physical systems to simulate a series of real life scenarios of using Symform (e.g., install, access, upload, download, view, delete, and uninstall) on various operating systems, as detailed in tables 1, 2, 3, and 4, and figures 2, 3, and 4. We used the base VMs as a control media to determine changes during each experiment. As explained by Quick and Choo [21, 22, 24], using physical hardware to undertake setup, erasing, copying, and re-installing would have been an onerous exercise. Moreover, a virtual machine allows room for error by enabling the test environment to be reverted to a restore point if the results are unfavorable. We configured the hard drive and RAM with minimal space in order to reduce the time required to analyse the considerable amounts of snapshots. Similar to the approaches of Quick and Choo [21, 22, 14, 24], we used the 3111^{th} and 13100^{th} email messages of the UC Berkeley Enron email dataset (downloaded from `http://bailando.sims.berkeley.edu/enron_email.html` on 24^{th} of September 2014) to create the sample files and saved in `.RTF, .TXT, .DOCX, .JPG` (print screen), `.ZIP`, and `.PDF` formats.

Immediately upon the completion of each experiment, we took a snapshot of each of the VMs after being shutdown in order to allow restoring at a later stage, if necessary. We remark that we captured the RAM immediately after each experiment, before the shutdown. As noted by Quick and Choo [21, 22], `.VMEM` files represent a capture of memory dump which is not being with the use of memory acquisition tools. Therefore, instead of acquiring RAM dump using live acquisition tools, e.g., 'win32dd' and 'FTK Imager', we captured the memory on a copy of the VMEM files created by VMware. A similar consideration was made in relation to creating a forensic copy of the hard drive; we instantiated the physical hard drive by the copy of the VMDK files created by VMware. Meanwhile, we facilitated the network traffic by the `.LIBPCAP` files captured using 'Wireshark'.

Table 1: Configurations of virtual machines for Symform web application analysis on Windows 8.1.

VM (Parent and child VMs)	**Details**
1.0 Base-VM 1.1 IE, 1.2 MF, 1.3 GC	We prepared a base VM running Windows 8.1 Professional (Service Pack 1, 64-bit, build 9600), and equipped with 2GB RAM and 20GB hard disk. We then installed three well-known browsers namely Microsoft Internet Explorer Version 11.0.9600.17351 (IE), Mozilla Firefox Version 33.1 (MF), and Google Chrome Version 37.0.2062.124m (GC) into three separate VMs duplicated from the base VM. We used a separate computer to create Symform account, configure a Windows device, and upload the sample files using the client application.
Access-VM 1.1.1 IE, 1.2.1 MF, 1.3.1 GC	We created a copy of each web browser base VM (1.0) and used to analyse the process of logging in Symform web application using the respective browsers on Windows 8.1.
Download/ Open-VM 1.1.2 IE, 1.2.2 MF, 1.3.2 GC	We created extra copies of the web browser base VMs (1.0) to examine the process of downloading and viewing files through each investigating web browser on Windows 8.1. We noted the creation, modification, and last accessed times of each file to detect changes in timestamps following file download.
Delete-VM 1.1.3 IE, 1.2.3 MF, 1.3.3 GC	We created additional copies of the web browser base VM (1.0) to investigate the artefacts of deleting synced files on the Symform web application.

Table 2: Configurations of virtual machines for Symform client application analysis on Windows 8.1.

VM (Parent and child VMs)	**Details**
1.4 Install-VM	Using a duplicate copy of the base VM (1.0), we accessed Symform website to download and subsequently install the Symform client application Version 4.24.0.0 (for Windows). (`http://www.symform.com/download/windows/`)
1.4.1 Access-VM	We made a copy of the install VM (1.4) to examine the process of logging in Symform account using the client application on Windows 8.1.
1.4.2 Upload-VM (Synchronise)	We made a copy of the install VM (1.4). We copied the Enron dataset files from the host machine to `C:\sync` (self-defined backup folder) of this VM and subsequently uploaded to the Symform server.
1.4.2.1 Uninstall-VM	We created a copy of the upload VM (1.4.2) to examine the process of uninstalling the Symform client application on Windows 8.1. We performed uninstallation using the default Windows uninstallation feature (`Control Panel\All Control Panel Items\Programs and Features`).
1.4.3 Download-VM (Synchronise)	We duplicated the install VM (1.4) (without being tainted with the dataset files) to examine the process of downloading or synchronising files using the Symform client application on Windows 8.1. We then downloaded all the files which were uploaded from the Upload-VM (1.4.2) to the `C:\sync` folder of this VM. We noted the creation, modification, and last accessed times of each file to detect changes in timestamps after transferring files.
1.4.3.1 Delete-VM (Synchronise)	We created a copy of the download VM (1.4.3) to assess the process of deleting files downloaded or synchronised using the Symform client application on Windows 8.1 (without emptying the Recycle Bin). No anti-forensic technique was applied to simulate a typical file-deleting situation.

Table 3: Configurations of virtual machines for Symform client application analysis on Ubuntu 14.04 LTS.

VM (Parent and child VMs)	**Details**
2.0 Base-VM	We prepared a base VM running Ubuntu 14.04 LTS, and equipped with 1GB RAM and 20GB hard disk.
2.1 Install-VM	We made a copy of the base VM (2.0) and used to access Symform website (`http://www.symform.com/download/linux/`) and download and subsequently install the Symform client application Version 4.24.0.0 (for Linux).
2.2 Access-VM	We created a copy of the install VM (2.1) to examine the process of logging in Symform account using the Symform client application. Since Symform (Linux) client application is a web GUI, we signed-in using the default Mozilla Firefox browser (Version 31.0) by accessing `http://127.0.0.1:59234/`.
2.3 Upload-VM (Synchronise)	We used a duplicate copy of the install VM (2.1) to undertake the file upload process on Ubuntu 14.04 LTS. We copied the Enron dataset files from the host machine to `/root/sync/` (self-defined backup folder) of this VM and subsequently uploaded to the Symform server.
2.3.1 Uninstall-VM	Using a duplicate copy of the upload VM (2.3), we uninstalled the Symform client application. We used the uninstallation commands (e.g., `sudo apt-get remove symform` and `sudo apt-get purge symform`).
2.4 Download-VM (Synchronise)	We duplicated the install VM (2.1) (without being tainted with the dataset files) to undertake the process of downloading or synchronising files using the Symform client application. We then downloaded all the files uploaded from the Upload-VM (2.3) to `/root/sync/` of this VM. We noted the creation, modification, and last accessed times of each file to detect changes in timestamps following file download.
2.4.1 Delete-VM (Synchronise)	We created a copy of the download VM (2.4), without emptying the Trash. We did not apply any anti-forensic technique to simulate a typical file-deleting situation.

Table 4: Configurations of virtual machines for Symform client application analysis on Mac OS X Mavericks 10.9.5.

VM (Parent and child VMs)	**Details**
3.0 Base-VM	We prepared a base VM running Mac OS X Mavericks 10.9.5, and equipped it with 1GB RAM and 60GB hard disk.
3.1 Install-VM	Similar to Windows 8.1, we duplicated the base VM (3.0) and used it to access Symform website (`http://www.symform.com/download/mac/`) to download and subsequently install the Symform client application Version 4.24.0.0 (for Mac).
3.2 Access-VM	We created a copy of the install VM (3.1) to examine the process of logging in Symform account using the client application and the web GUI on Mac OS X Mavericks 10.9.5.
3.3 Upload-VM (Synchronise)	We created a duplicate copy of the install VM (3.1) and used it to undertake file upload through the Symform client application. We copied the Enron dataset files from the host machine to `/Users/[User Profile]/sync/` (self-defined backup folder) of this VM and subsequently uploaded it to the Symform server.
3.3.1 Uninstall-VM	Using a duplicate copy of the upload VM (3.3), we uninstalled the Symform client application by the uninstallation commands for Mac OS (e.g., `sudo/Library/Application\Support/Symform/scripts /uninstall` and `sudo/Library/Application\Support/Symform/scripts /uninstall-purge`).
3.4 Download-VM (Synchronise)	We duplicated the install VM (3.1) (without being tainted with the dataset files) to examine the process of downloading or synchronising files. In this VM, we downloaded all the uploaded files from the upload VM (3.3) to `/Users/[User Profile]/sync/` of this VM. We noted the creation, modification, and last accessed times of each file to detect changes in the timestamps after undertaking file download.
3.4.1 Delete-VM (Synchronise)	We created a copy of the download VM (3.4) to assess the process of deleting the files downloaded or synchronised (without emptying the Trash). We did not apply any anti-forensic technique to simulate a typical file-deleting situation.

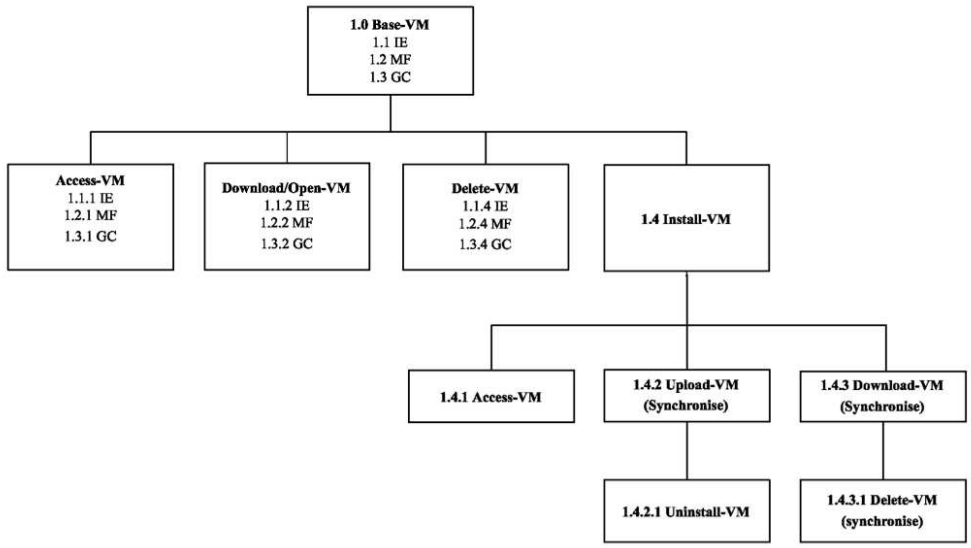


Figure 2: VMs created for Symform investigation on Windows 8.1.

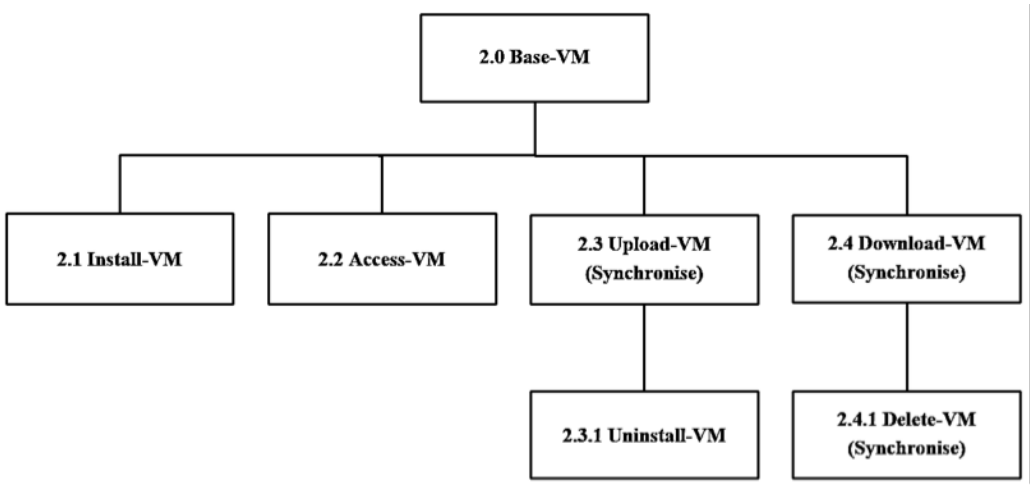


Figure 3: VMs created for Symform investigation on Ubuntu 14.04 LTS.

230 In order to analyse the Symform mobile app, we prepared a default factory restored iPhone 4 running iOS 7.1.2 and an HTC One X running Android KitKat 4.4 to simulate the use of the Symform app on both devices. To gain root access to the devices, we jailbroke the iOS device using 'Pangu8 Version 1.1' and rooted the Android device using 'Odin3 Version 185'. To

examine the manner in which the file systems were treated with respect to the installation and viewing of files (the only feature supported by the mobile apps) and the uninstallation of the Symform apps, we created a binary image of the mobile devices for different Symform usage scenarios using 'dd' over SSH/ADB Shell. In particular, we took the first image prior to the installation of the Symform apps to ensure that neither Symform nor Enron-related data were on the devices. Then we installed the Symform iOS app Version 1.13 and Android app Version 1.3 on the respective devices and took the second image of each device. Moreover, we took another image of the devices after viewing the dataset files in the Symform apps. Then we made the final image following the uninstallation of the apps.

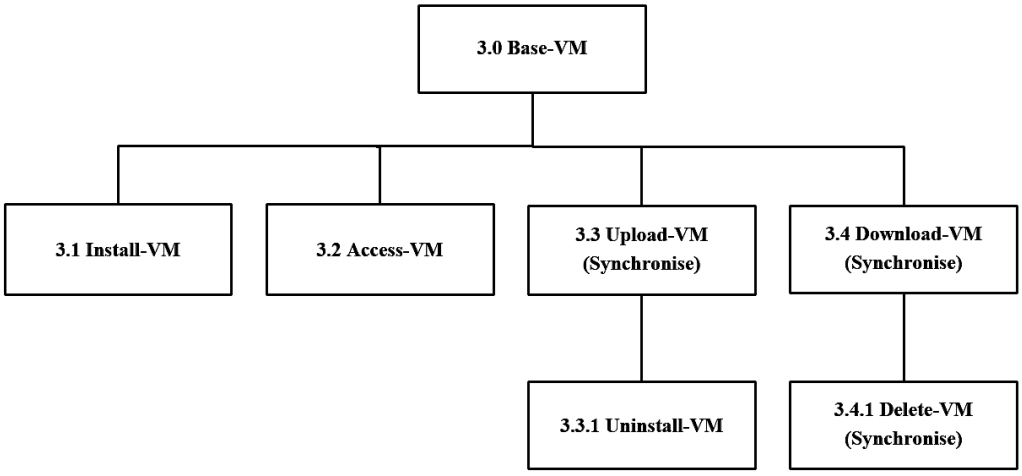


Figure 4: VMs created for Symform investigation on Mac OS X Mavericks 10.9.5.

'Wireshark' was hosted on the host machine to capture the network traffic of the suspect's VM; started prior each experiment was carried out, and we saved a copy of the network capture after carrying out each experiment. To ensure consistency of the findings, we conducted each experiment at least thrice on different dates. Table 5 details the tools prepared to undertake this research.

Table 5: Tools prepared.

Tool	Usage
FTK Imager v3.2.0.0	To create forensic images for `.VMDK` and `.VMEM` files.
dd v1.3.4-1	To produce the bit-for-bit images of the internal storage of the mobile devices.
emf_decrypter.py	To decrypt the iOS images acquired for analysis.
Autopsy 3.1.1	To parse the file system, produce directory listings, and extracting or analysing images of the mobile devices, stored files, browsing history, swap files, unallocated partitions, as well as Windows system files, e.g., `NTUSER.dat` registry files (using the RegRipper plugin) and `pagefile.sys` Windows swap files, located within the forensics images of `.VMDK` files.
HxD v1.7.7.0	To conduct keyword searches in `.VMEM` files.
Volatility 2.4	To analyse running processes (using the pslist function), network information (using the netscan function), and detecting the location of a string (using the yarascan function) in physical memory dumps.
SQLite Browser v3.4.0	To view the contents of SQLite database files.
Wireshark v1.10.1	To analyse network files.
Network Miner v1.6.1	To analyse and carve network files.
Whois command	To determine the registration information of an IP address.
Photorec 7.0	To undertake data carving of memory files.
Nirsoft Web Browser Passview v1.58	To recover the credential details stored within web browsers.
Nirsoft cache viewer, ChromeCacheView 1.56, MozillaCacheView 1.62, IECacheView 1.53	To parse and analyse web browsers' cache files.
BrowsingHistoryView v1.60	To parse and analyse web browsers' history files.
Thumbcacheviewer v1.0.2.7	To view the thumbnail images stored in Windows thumbcache folder.
Windows Event Viewer v1.0	To view Windows event files.
Console v10.10 (543)	To view Mac-OS-specific log files (e.g., Apple System Logs).
Windows File Analyser 2.6.0.0	To analyse Windows prefetch and link files.
Plist Explorer v1.0	To examine the contents of Apple Plist files.
chainbreaker.py	To recover the master keys stored in Mac's Keychain dump.
NTFS Log Tracker	To parse and analyse the `$LogFile`, `$MFT`, and `$UsnJrnl` New Technology File System (NTFS) files.

3. Collection and timestamp analysis

Before undertaking analysis into Symform, we collected data that would potentially contain information of interest for cloud forensics (e.g., sync and file management metadata, caches, cloud service and authentication data, encryption metadata, browser artefacts, mobile artefacts, as well as network artefacts) as identified by Martini and Choo [46]. These included files stored within unallocated partitions, swap files, log files (e.g., system logs stored under `%Windows% \system32\config` on Windows machine, `/var/log` on Ubuntu machine, `/private/var/log` on Mac OS machine, and Symform log files), thumbcache files, preference files (e.g., property list –Plist– files stored within `/Users/[User profile]/Library/Preferences/` of Mac OS), Symform sync folders, web browser files, and Windows system files (e.g., `$LogFile`, `$MFT`, `$UsnJrnl`, `NTUSER.dat`, prefetch files, thumbcache files, link files, as well as other installation and user-specific preference files saved under `%ProgramFiles% \%AppData% \`). The network traffic and RAM captures were facilitated by the `.LIBPCAP` and `.VMEM` (preserved in AD1 format) files captured in our research, respectively.

During our collection of the downloaded/synced files on Windows 8.1, we observed that the last accessed and last modified times were the times when the files were downloaded. However, the last written times retained its original value unchanged. On Ubuntu, we observed that the modification, creation, and last opened times remained unchanged. On the other hand, the added times were the times when the files were downloaded to the machine. An inspection of the timestamps of the downloaded files on Mac OS determined that the modified times remained unchanged while the accessed times matched the download times. Of all the OS investigated, the MD5 and SHA1 hash values for the downloaded files remained the same as the original values in all experiments, which suggested that no alteration was made during transmission of the files.

4. Symform analysis on computer devices

In this section, we present the findings of our analysis on Windows 8.1, Ubuntu 14.04 LTS, and Mac OS X Mavericks 10.9.5. Symform artefacts collected included data remnants within the directory listings, log files, browser files, thumbnail cache, RAM, swap file/partition, unallocated space, as well as Windows system files (e.g., registry files, `pagefile.sys`, link files, and prefetch files).

4.1. Directory listings and files of forensic interest

The directory information is essential when seeking to determine if an application has been used to initiate further investigation. An examination of the control base VMs (1.0 Windows Base-VM, 1.1 IE, 1.2 MF, 1.3 GC, 2.0 Ubuntu Base-VM, and 3.0 Mac Base-VM) confirmed that there was no data related to Symform and the Enron emails on these VMs. Therefore, any Symform-related data recovered from the remaining VMs would indicate Symform usage.

4.1.1. Windows 8.1

The main starting point of Symform investigation on Windows machine is in `%Program Files% \Symform\`. The folder of particular interest is the `%Program Files% \Symform\Node Service\logs` folder, which maintains a list of Symform log files useful to assist forensic practitioners in scoping the investigation (see Section 4.2). Meanwhile, the `%Program File% \Symform\Node Service\node.config` XML file stores a wealth of node-specific configuration details for the file synchronisation and contribution services, which include the server address for the cloud management service (prefixed with *'serverAddress'*), unique SHA-1 node ID (prefixed with *'nodeId'* in the *node* tag), encrypted secret key (prefixed with '*secretKey=*' in the *node* tag) in base64 format, login username or email address (prefixed with '*username=*' in the *userCredentials* tag), encrypted password (prefixed with '*password=*' in the *userCredentials* tag) in base64 format, location of the contribution folder (prefixed with '*fragmentStorePath=*' in the *contribution* tag), port number of the contribution service (prefixed with '*port=*' in the *contribution* tag), as well as bandwidth limits (prefixed with '*uploadBandwidthCapacity=*' and '*downloadBandwidthCapacity=*' in the *node* tag respectively).

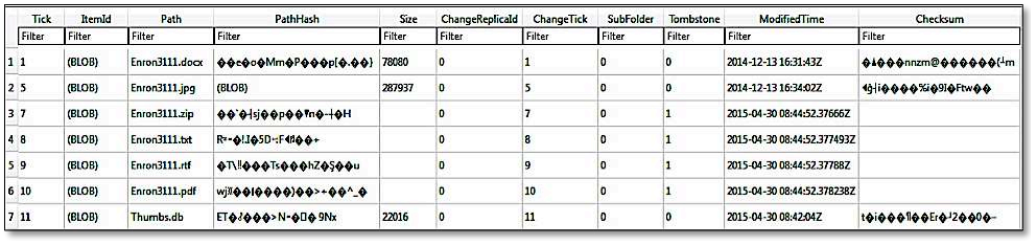
Moreover, within the *folderMapping* tag we found an opening and closing *folder* sub-tag for the sync folder, which contain information such as the folder global ID of a sync folder (prefixed with *'remoteFolderGlobalId'*), the folder path (prefixed with '*localPath=*'), the remote folder name (prefixed with '*remoteFolderName=*'), and the folder editing permission (prefixed with '*direction=*') see Figure 5. Such information would be useful in identifying a user's self-defined sync folder(s). The node and FolderGlobal IDs could also assist investigators in correlating any external data obtained from an Internet service provider (ISP) or other external content or service provider.

Figure 5: Content of `node.config` File (valuable remnants are bolded).

In our experiments, we determined that when a sync folder was configured, two hidden subfolders (`.symform` and `.symform-store`) would be created in the sync folder to store the synced file caches. The file of particular interest is the *metadata* sqlite3 database in the `.symform` subfolder, which maintains a list of synced file metadata such as synced filenames as well as their sizes, last modified times, and checksums in the *FolderItem* Table. The metadata remained in the database even after the synced files had been deleted, and the deleted files could be discerned from entries with empty *Size* and *Checksum* table fields. Figure 6 shows an example of the *FolderItem* Table of metadata database containing entries for deleted files namely `Enron3111.zip`, `Enron3111.txt`, `Enron3111.rtf`, and `Enron3111.pdf`. The findings also suggest that when a user uses Symform, there will be references to the creation or removal of the sync folder remaining in the NTFS files (e.g., `$LogFile`, `$MFT`, and `$UsnJrnl`) that can be used to identify its usage or synced files; an example of the `$LogFile` entries is shown in Figure 7.

Located within the `%SymformContribution%` folder were subfolders storing fragments of backup files from peer nodes. The file fragments were represented by the unique IDs with the following naming convention: `[Unique SHA-1 for a file fragment].[File fragment number].[Folder global ID]` (e.g., `0A1D16AF1E451120F32399828FEAEE3A8797XXXX.067.0000000220035142XXXX`). However, the shredded and encrypted file fragments mean the actual files are not recoverable without the assistance from cloud service provider. In ad-

dition, the presence of Symform executable files in `%AppData% \Local\Temp\` would suggest recent Symform usage.



	Tick	ItemId	Path	PathHash	Size	ChangeReplicaId	ChangeTick	SubFolder	Tombstone	ModifiedTime	Checksum
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	1	(BLOB)	Enron3111.docx	◆◆c◆o◆Mm◆P◆◆◆p[◆.◆◆}	78080	0	1	0	0	2014-12-13 16:31:43Z	◆↓◆◆◆nnzm@◆◆◆◆◆◆{↳m
2	5	(BLOB)	Enron3111.jpg	(BLOB)	287937	0	5	0	0	2014-12-13 16:34:02Z	↰¡i◆◆◆◆%i◆9l◆Ftw◆◆
3	7	(BLOB)	Enron3111.zip	◆◆'◆┤sj◆◆p◆◆¶n◆-┤◆H		0	7	0	1	2015-04-30 08:44:52.37666Z	
4	8	(BLOB)	Enron3111.txt	R▫-◆JI◆5D-;F4t◆◆+		0	8	0	1	2015-04-30 08:44:52.377493Z	
5	9	(BLOB)	Enron3111.rtf	◆T\‼◆◆◆Ts◆◆◆hZ◆Ş◆◆u		0	9	0	1	2015-04-30 08:44:52.37788Z	
6	10	(BLOB)	Enron3111.pdf	wjll◆◆I◆◆◆◆)◆◆>▫◆◆^_◆		0	10	0	1	2015-04-30 08:44:52.378238Z	
7	11	(BLOB)	Thumbs.db	ET◆♪◆◆◆>N~◆□◆.9Nx	22016	0	11	0	0	2015-04-30 08:42:04Z	t◆i◆◆◆¶◆◆Er◆♪2◆◆0◆~

Figure 6: The 'FolderItem' Table of metadata database.

LSN	Event Time	Event	Detail	File Name	Full Path(from $MFT)	Create Time	Modified Time	MFT_Modified Time	Access Time	Redo
286406888		Moving Before		ftfdc2rb.ffm	\sync\.symform\ftfdc2rb.ffm					Delete Attribute
286406934		Moving After		3111.jpg	\sync\3111.jpg					Create Attribute
286407730	2015-01-08 00:40:21	File Creation		eslqs_8lf7a32rXiZbM4j	\Windows\Temp\eslqs_8lf7a32rXiZbM4j	2015-01-08 00:40:21	2015-01-08 00:40:21	2015-01-08 00:40:21	2015-01-08 00:40:21	Initialize File Rec
286408405		File Deletion		eslqs_8lf7a32rXiZbM4j	\Windows\Temp\eslqs_8lf7a32rXiZbM4j	2015-01-08 00:40:21	2015-01-08 00:40:21	2015-01-08 00:40:21	2015-01-08 00:40:21	Deallocate File R
286408532				3111.jpg	\sync\3111.jpg	2015-01-08 00:40:21	2004-11-10 21:40:51	2015-01-08 00:40:21	2015-01-08 00:40:21	Set New Attribut
286408682	2015-01-08 00:40:23	Directory Creation		2D097E17B36DDF1A.A3360DA4...	\sync\.symform\temp\2D097E17B36DDF1A.A3360DA...	2015-01-08 00:40:22	2015-01-08 00:40:22	2015-01-08 00:40:23	2015-01-08 00:40:23	Initialize File Rec
286409062	2015-01-08 00:40:23	File Creation		s3ZrSrt.dtd		2015-01-08 00:40:23	2015-01-08 00:40:23	2015-01-08 00:40:23	2015-01-08 00:40:23	Initialize File Rec
286409324		Writing Content of Non-Resident File	Cluster Number : 2706568(1)	s3ZrSrt.dtd						Update Mapping
286409565	2015-01-08 00:40:23	Directory Creation		2D097E17B36DDF1A.A3360DA4...	\sync\.symform\download\2D097E17B36DDF1A.A336...	2015-01-08 00:40:23	2015-01-08 00:40:23	2015-01-08 00:40:23	2015-01-08 00:40:23	Initialize File Rec
286409902		Moving Before		s3ZrSrt.dtd						Delete Attribute

Figure 7: `$LogFile` entries containing references to the creation of Symform sync folder.

The files downloaded through the web browsers were stored in `%Downloads% \` by default. We observed that each downloaded file was given an Alternate Data Stream (ADS) ZoneTransfer marker (ZoneID) with reading '*ZoneID=3*', which indicates that the files were downloaded from Internet zone [56]. The ADS ZoneID is useful to determine the origin of a synced file especially in the absence of the Internet browsing history. The deleted files along with the original extensions and ADS ZoneIDs (when downloaded using a browser) could be recovered from the non-emptied `% $Recycle.Bin% \SID` folder, only if the forensic practitioner is aware that the filenames had been renamed to `$R` and `$I` followed by a set of random characters. Information relating to the original files, such as the original paths, sizes, and delete times, could also be recovered from the `$R` and `$I` files.

Undertaking uninstallation of the Symform client application, we determined that `%Program File% \Symform\`, `%AppData% \Local\Temp\Symform\`, and `%SymformContribution% \` remained on the hard drive, but they were empty. However, we identified that the `.symform` and `.symform-store` cache folders were not removed from the sync folder, which included the *metadata* database located within

the `.symform` cache folder. These artefacts could be useful for ascertaining the sync folder and recovery of the synced file history after uninstallation of the client application, since a typical user would not manually delete the cache folders (hidden by default). In addition, the uninstallation could be ascertained from the presence of entries referencing removal of the client application filenames in the `$LogFile`, `$MFT`, and `$UsnJrnl` NTFS files.

4.1.2. Ubuntu 14.04 LTS

An examination of the directory listing of the Install-VM (2.1) revealed that the main installation directory of the Linux Symform application could be located in `/opt/symform/` by default. Of particular interest is the `/opt/symform/bin/logs` subfolder which stores various Symform logs (see Section 4.2.4). In addition, we located copies of the log files in `/var/log/symform/`. A list of certificates used by Symform stored within the `/var/lib/symform/.mono/certs/Trust` folder and the user keypair metadata (e.g., the base64-encoded values of the P, Q, DP DQ, InverseQ, and D keys of the RSA algorithm used by Symform) could be located in the `/var/lib/symform/.mono/keypairs` folder.

The Symform contribution folder and `node.config` file (see Section 4.1) could be located in `/SymformContribution/` and `/var/lib/symform/` respectively. Similar to the Symform client application for Windows, we identified that when a sync folder is set up on Ubuntu OS, two hidden cache folders (`.symform` and `.symform-store`) will be created to store the sync file caches. The `/home/[User Profile]/.local/share/Trash/files` trash folder, when not emptied, would enable the recovery of deleted synced files. Additionally, the original file path and deletion time of each deleted file could be recovered from the `.TRASHINFO` file located in `/home/[User Profile]/.local/share/Trash/info/` – see Figure 8. When the uninstallation occurred, we observed that the `/opt/symform`, `/var/log/symform`, and `/var/lib/symform` folders were emptied. However, forensic practitioners could potentially recover the synced file history from the *metadata* database remained in the `.symform` cache folder (of each sync folder).

4.1.3. Mac OS X Mavericks 10.9.5

The main installation directory of the Symform client application for Mac OS is in `/Library/Application Support/Symform/`. The `/Library/Application Support/Symform/bin/logs/` directory maintains a list of Symform logs. This would enable forensic practitioners to obtain

relevant Symform usage information (see Section 4.2.4). Alternatively, a copy of the *logs* folder could be located in `/private/var/logs/Symform/`. The `node.config` file, *Trust* folder (which contains a list of certificates used by Symform), and *keypairs* folder (that contains the user keypair information as outlined in Section 4.1.2) could also be located in `/private/var/lib/symform/`.

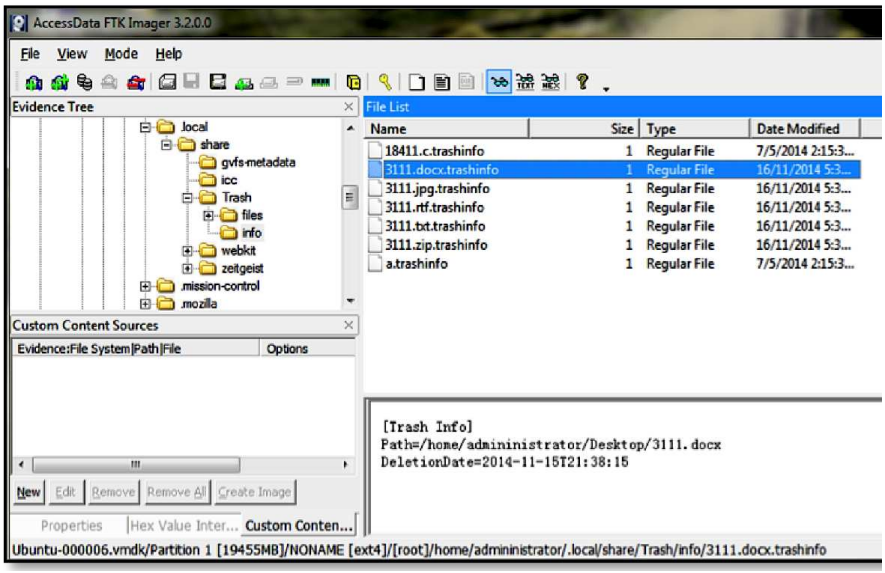


Figure 8: Trash info for deleted files in Linux.

When the file synchronisation occurred, we were able to recover copies of the `node.config` file from the `receiver_data` table field of the `cfurl_cache_receiver_data` table of `Cache.db` database located in `/Users/[User Profile]/Library/Caches/com.symform.mac.Symform`. Also located in the same table field were additional details relating to the file synchronisation sessions such as number of syncing folders, number and sizes of syncing files, file transfer speeds, remote folder names, local folder names, the estimated sync durations, and the service start times. In addition, the `cfurl_cache_response` table of `Cache.db` maintains a list of Symform URLs as well as the corresponding timestamps (see Figure 9). Forensic practitioners could potentially discern the start and stop timestamps for the sync service from the timestamps of the `request_key` entries referencing `http://localhost:[Portnumber]/syncService/start` and `http://localhost:[Portnumber]/syncService/stop` respectively.

Alternatively, references to the download links for the installer and synced files could be potentially recovered from the `/Users/[User Profile]/Library/Preference/com.apple.LaunchServices.QuarantineEventsV2` sqlite3 database.

	entry_ID	version	hash_value	storage_policy	request_key	time_stamp	partition
	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	1	0	-4882646443614...	0	http://www.google-analytics.com/collect?non=16807&t=pageview&uid=1061028722985928dt=applicationDidFinishLaunching&v=1&dh=osapp.symform.com&dp=/applicationDidFinishLau...	2014-11-16 00:55:51	
2	2	0	1873888079	0	http://localhost:59245/syncService	2014-11-16 00:55:51	
3	3	0	-6262528257604...	0	http://www.google-analytics.com/collect?non=2824725498t=pageview&uid=1061028722985928dt=setup-welcome&v=1&dh=osapp.symform.com&dp=/setup-welcome&tid=UA-18085020...	2014-11-16 00:55:51	
4	4	0	1565549121764...	0	http://www.google-analytics.com/collect?non=1622650073&t=pageview&uid=1061028722985928dt=setup-account-login-create&v=1&dh=osapp.symform.com&dp=/setup-account-login-...	2014-11-16 00:56:21	
5	5	0	1115225802272...	0	http://www.google-analytics.com/collect?non=1115438165&t=pageview&uid=1061028722985928dt=setup-node&v=1&dh=osapp.symform.com&dp=/setup-node&tid=UA-18085020-1&cid...	2014-11-16 00:56:40	
6	6	0	3864459746529...	0	http://www.google-analytics.com/collect?non=1784484492&t=pageview&uid=1061028722985928dt=setup-folders-remote-step1&v=1&dh=osapp.symform.com&dp=/setup-folders-remote...	2014-11-16 00:56:48	
7	7	0	-7846333405042...	0	http://www.google-analytics.com/collect?non=742430428t=pageview&uid=1061028722985928dt=setup-folders-remote-step2&v=1&dh=osapp.symform.com&dp=/setup-folders-remote-st...	2014-11-16 00:57:03	
8	8	0	5765741029894...	0	http://www.google-analytics.com/collect?non=114807987&t=pageview&uid=1061028722985928dt=setup-done&v=1&dh=osapp.symform.com&dp=/setup-done&tid=UA-18085020-1&cid=...	2014-11-16 00:57:18	
9	9	0	5835618353120...	0	http://localhost:59245/syncService/stop	2014-11-16 00:57:35	
10	10	0	1262687272718...	0	http://localhost:59245/syncService/start	2014-11-16 00:57:41	
11	11	0	-8022314490295...	0	http://localhost:59245/nodeConfig	2014-11-16 00:57:41	
12	12	0	-1337573208	0	http://localhost:59245/metrics	2014-11-16 00:57:51	
13	13	0	-1761597220866...	0	http://www.google-analytics.com/collect?non=952954967&t=pageview&uid=1061028722985928dt=menulet-panel&v=1&dh=osapp.symform.com&dp=/menulet-panel&tid=UA-18085020-1...	2014-11-16 00:57:51	

Figure 9: The `cfurl_cache_response` Table of `Cache.db`.

Similar to the Windows and Linux investigations, setting up of a Symform sync folder in Mac OS observed that two hidden cache folders (`.symform` and `.symform-store`) will be present. The deleted files were located in the non-emptied `/Users/[User profile]/.Trash` folder. Although the uninstallation would empty the `/Library/ApplicationSupport/symform` and `/SymformContribution` folders, the synced file history could be potentially recovered from the *metadata* Database remained in the `.symform` cache folder (of each sync folder).

4.2. Log files

Logs play a vital role in an incident investigation [57]. The log analysis in this research included searching for the term *Symform* and the *Enron* dataset filenames as well as going through the entries identifying events relevant to Symform.

4.2.1. Windows 8.1

Similar to any other Windows application, when the Symform client application was installed or uninstalled on Windows 8.1, we located event entries referencing the installation or uninstallation of the services as well as the associated timestamps in Windows event files such as `Application.evtx` and `System.evtx` (see Figure 10) saved in `%Windows% \system32\config\`. When file synchronisation took place via the client application, there were

entries referencing *symformsync* in the aforementioned Windows event files (see Figure 11).

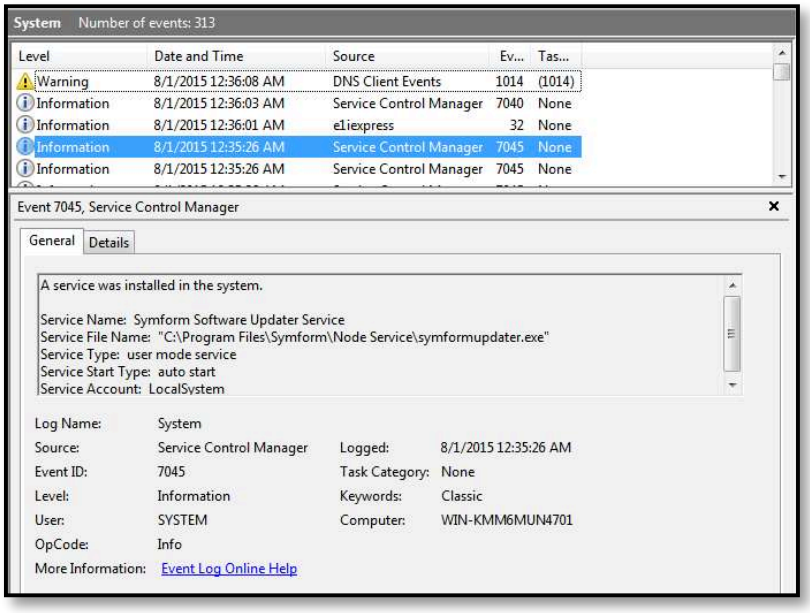


Figure 10: Windows event log entry for Symform installation.

4.2.2. Ubuntu 14.04 LTS

Log files are particularly important in Linux investigations as almost all processes, events, and user account activities are logged [58]. When the Symform installation occurred on a Linux machine, forensic practitioners could potentially recover events relating to the creation of Symform services from the `/var/log/syslog`. Further information about the installation could be located in the `/var/log/dpkg.log`, since the log file maintains a list of events relating to the `Symform.deb` installer package such as the Symform version installed, installation status (e.g., unpacked, configured, and installed) as well as the corresponding installation time. Moreover, the `/var/log/auth.log` would provide information associated with the authorisation (granting *superuser* permission) details for Symform installation sessions, the paths accessed during the installation, and the corresponding installation time. The term *Symform* could be used in future searches.

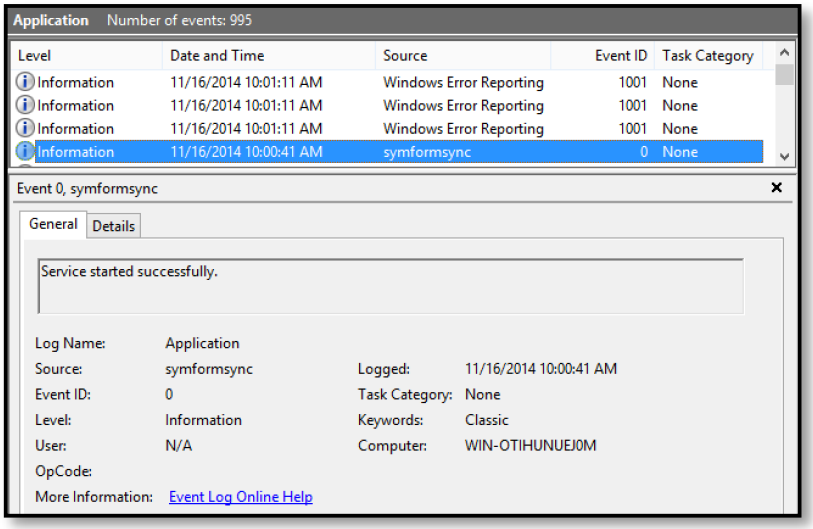


Figure 11: Windows event log entry for Symform sync service.

4.2.3. Mac OS X Mavericks 10.9.5

The installation or use of the Symform client application on a Mac machine could be discerned from the presence of Kernel and system events (e.g., program errors, installation data, privilege escalation) for the Symform main services in the `/private/var/log/system.log` log file, which contains information of interest such as the Symform application name, PID, and path references for the main services. Similar information could be found in the Apple System Logs (ASL) located at `/private/var/log/asl/YYYY.MM.DD.[User identification].[Group identification].asl` (where user identification (UID) and group identification (GID) are optional). Further information of the installation could be located in `/private/var/log/install.log`, which contains entries relating to the installation of the client application such as filename of the installer, the Symform version installed, as well as the time of installation. The term *Symform* could be used in future searches.

4.2.4. Symform logs

We determined that Symform logs were stored in `%Program Files% \Symform\Node Service\logs\` on Windows machine, `/var/log/symform/` on Ubuntu machine, and `/var/log/symform/` on Mac OS machine unencrypted. We also determined that by default, the logs would be archived hourly in compressed `.GZ` format and kept for a

month before being deleted, with the exception of the setup logs (e.g., `symformsetup.log`, `symformupdater.log`, and `loguploader.log`). As the filename suggests, the `symformsetup.log` maintains a list of the client application setup information such as the version of the Symform client application installed, email addresses used to login the client application, login URLs, the full path(s) of the sync folder(s), as well as the installation time, which could be a potential starting point for Symform investigation.

The `symformsync.log`, `symformsync-mono.log`, `symformcontrib.log`, and `symformcontrib-mono.log` store a wealth of events relating to the Symform client application usage, comprising references to the `node.config` file path, copies of the `node.config` file, types of cryptographic algorithms used (e.g., *MD5CryptoServiceProvider*, *SHA1CryptoServiceProvider*, *SHA256Cng*, and *AesCryptoServiceProvider*), as well as the network details (e.g., download and upload speeds and its bandwidth limits). In addition, the filename and path references for the downloaded or uploaded files, request IDs for the backup file fragments, file synchronisation statuses, port numbers used by the file synchronisation services, as well as the times when the file synchronisation services were started and terminated could be recovered from the `symformsync.log` and `symformsync-mono.log` (see Figure 12). The terms *download*, *downloading*, *starting download session*, *upload*, *uploading*, *starting upload session*, *syncing*, and *preparing* could be used to locate the synced file details. Meanwhile, the node configuration information could be discerned from log entries referencing the term *SyncHost*, while the external IP addresses used by the host could be located using the term *LastSeenIPAddress*. Within the `symformcontrib.log` and `symformcontrib-mono.log` there exists additional information relating to the contribution service such as the full path of the contribution folder, the port number for the contribution service, the times when the contribution service was started or terminated, as well as the external IP addresses of the corresponding nodes. The timestamp information noted along the log entries could be used for timeline or super timeline analysis [59].

When we accessed Symform on Ubuntu, we located references to the directories accessed and created by the Symform client application in the `/var/lib/dpkg/info/symform.list` log file, which is useful when seeking to determine the installation and sync folder paths. In addition, the `symformcloudcache.log` (found only in Mac OS) maintains a list of HTTP requests for retrieving or updating the account or client-device information from or to the server along with the associated timestamps (see Figure 13).

Figure 12: An excerpt of `symformsync.log` recovered from our research.

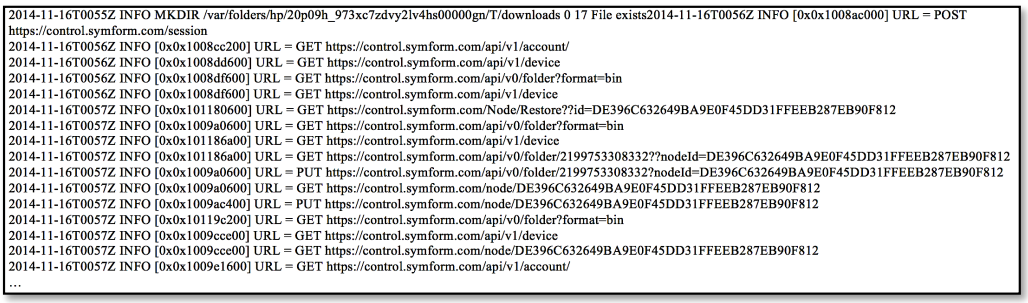


Figure 13: An excerpt of `symformcloudcache.log`.

4.3. Thumbnail cache

Thumbnail cache is a potential alternative source for recovery of images relevant to an investigation [60]. Analysis of the Thumbcache files stored under `%AppData% \Local\Microsoft\Windows\Explorer\` of the Install-VM (1.4) and Access-VM (1.4.1, 1.1.1 IE, 1.2.1 MF, and 1.3.1 GC) located copies of thumbnail images for the client or web application such as Symform logo and image icons appeared on the GUI. When the sample files were synced, we located copies of the thumbnail images in the Windows Thumbcache files. However, no thumbnail relevant to Symform was located in the Ubuntu and Mac OS VMs.

4.4. Web browser artefacts

Web browsing information is another potential source of information in cloud investigations [21, 22, 24, 46]. In this section, we present the artefacts of the Symform web application and RDM recovered in our experiments.

4.4.1. Symform web application

Symform only allows users to download or delete files through its web application interface. Whilst accessing the web application, we observed that the username could be located at the top right corner of the browser. The web application retains a record of devices/nodes linked with an account in the left-hand pane of the browser. When we select a device, the web application will display the backup folders/files associated with the device. When hovered over an inactive device (marked with X), a message "Device has not been reported in XX days" will be displayed. The web application also has an option to show or restore deleted files (within 7 days of deletion). Unlike Dropbox and Google Drive investigated by Quick and Choo [21, 22], other than the duration (in days) from the last modified date, Symform web application does not show timestamp information such as last accessed time, file creation time, and last written time of the backup files.

Similar to any other web application, accessing Symform through a web browser would leave URLs referencing `www.symform.com` alongside the associated timestamp information and view counts in the browsing history. When we logged in Symform, we observed the URL `control.symform.com` in the web browsing history, as well as the download link `content.symform.com/api/v0/folder/[Folder global ID]/[Filename]` when we performed file download. When we accessed Symform using Google Chrome, we located the aforementioned URLs

in the *thumbnails* Table of the `%AppData% \Local\Google\Chrome\User Data\Default\Top Sites` database, indicative of frequent Symform usage. Moreover, the presence of the URLs aforementioned in the `%AppData% \Local\Google\Chrome\User Data\Default\Current Tabs` and `%AppData% \Local\Google\Chrome\User Data\Default\Last Session` files of Google Chrome, `%AppData% \Roaming\Mozilla\Firefox\Profiles\%PROFILE%.default\ sessionstore.js` of Mozilla Firefox, as well as `%AppData%\Local\Microsoft\Windows\WebCache\V01.log` and `%AppData%\Local\Microsoft\Windows\WebCache\WebCacheV01.dat` of Internet Explorer would suggest recent Symform usage.

Within the web caches of all the investigating web browsers, we located the intact copies of downloaded files (Figure 14) as well as Symform images, HTML, Cascading Style Sheets (CSS), and Javascripts referencing *Symform* used by the web application, which included the last access timestamp information for the cache files. Additionally, when we closed the Mozilla Firefox tab for Symform, we could locate thumbnail images for Symform page in `%AppData%\Roaming\Mozilla\Firefox\Profiles\%PROFILE%.default\ thumbnails\`.

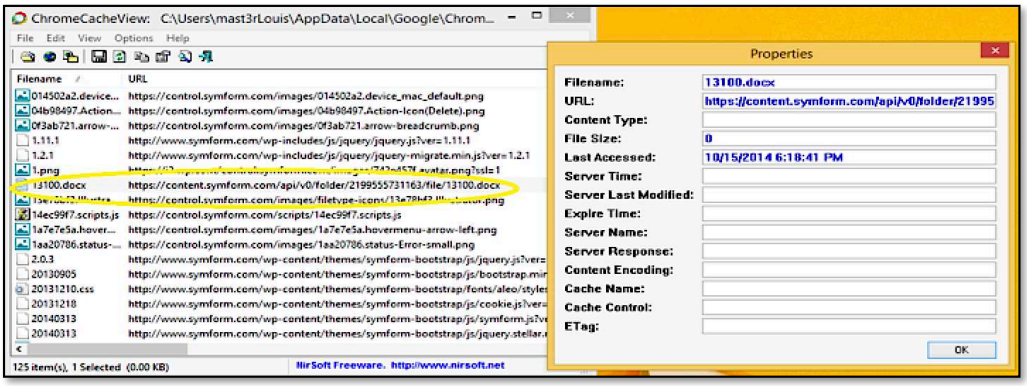


Figure 14: A copy Symform downloaded sample file recovered from Google Chrome browsing cache.

We could recover the login credentials (if saved) easily using tools like Nirsoft Web Browser Passview [61]. We determined that in Google Chrome, the credential details (login email

and encrypted password) are stored in the *Login Data* and *Web Data* files located under `%AppData% \Local\Google\Chrome\User Data\Default\`. Meanwhile, the credential details can be located in the `formhistory.sqlite` database and `logins.json` file under `%Users% \user\AppData\Roaming\Mozilla\Firefox\Profiles\` when saved in Mozilla Firefox. The login credentials recovered could facilitate user profiling and the accessing of the relevant accounts or applications.

4.4.2. Remote Device Manager

In this research, we accessed the RDM using Mozilla Firefox v3.10 (the default Ubuntu web browser) on Ubuntu and the inbuilt Apple Safari browser (Version 7.0.6 (9537.78.2)) on the Mac OS machine. When we set up the client application using the RDM on Ubuntu, we recovered URLs making reference to `127.0.0.1:59234/tour`, `127.0.0.1:59234/setup`, and `127.0.0.1:59234/setup/done` in the browsing history and `sessionstore.js` file located in `/home/[User profile]/.mozilla/firefox/[Random ID].default/`, which comprised the associated timestamp information and view counts (in the former). When the sign-in occurred, we located URLs referencing `127.0.0.1:59234/login` and `127.0.0.1:59234/general` in the Ubuntu Mozilla Firefox files aforementioned as well as `/Users/[User Profile /Library/Caches/Metadata/Safari/History.plist` Safari history file (when accessed on Mac OS). Additionally, we located a thumbnail image (screenshot) of the RDM webpage which appeared on the new tab page of Safari in `/Users/[User Profile/Library/Caches/com.apple.Safari/Webpage Previews/`. This is indicative of Symform usage.

4.5. Memory analysis

Memory forensics allow one to recover volatile information which would otherwise be lost [62]. In this research, we undertook data carving using Photorec, keyword search using Hex Workshop, and contextualising the RAM contents using Volatility.

When we analysed the running processes using the `pslist`, `linux_pslist`, and `mac_pslist` functions of Volatility, we recovered several process instances for Symform services, which included the process names (e.g., `symformstatus.exe`, `symformupdater.exe`, `symformcontrib.exe`, and `symformsync.exe` on Windows 8.1; `symformstatus`, `symformupdater`, `symformcontrib`, and `symformsync` on Ubuntu; `symform` on Mac), process

identifiers (PIDs), parent process identifiers (PPIDs), and the process initiation times; Figure 15 shows an example of the Windows processes. Our analysis also showed that the Symform processes are amalgamated into a single process, namely *Symform* on the Mac OS machine (in comparison with the process names presented for the Windows and Linux client applications). The PIDs could assist the investigator in obtaining data associated with the Symform client application during further analysis of the RAM (i.e., mapping a string of relevance to the instances resided in the memory space of the PID using the *yarascan* Function of Volatility). Analysing the network details using the `netscan`, `netstat_linux`, and `netstat_mac` functions of Volatility, we observed that the local, foreign, and peer node IP addresses could be recovered, which included its port numbers, socket states, PIDs, and process names. Such information is particularly useful for timeline analysis as well as in requests for assistance from counterparts overseas (e.g., via Interpol).

Offset(V)	Name	PID	PPID	Thds	Hnds	Sess	Wow64	Start	Exit
0xfffffa801a4b5940	services.exe	688	652	8	0	0	0	2014-11-15 17:55:14 UTC+0000	
0xfffffa801b5c0940	explorer.exe	1200	1848	53	0	1	0	2014-11-15 17:56:01 UTC+0000	
0xfffffa801b557080	symformstatus.exe.	3232	1200	16	0	1	0	2014-11-15 17:56:27 UTC+0000	
0xfffffa801a5b2940	symformupdater.exe	700	688	10	0	0	0	2014-11-15 17:58:40 UTC+0000	
0xfffffa801914a940	symformcontrib.exe	3704	688	15	0	0	0	2014-11-16 02:18:37 UTC+0000	
0xfffffa801b7af940	symformsync.exe	2488	688	21	0	0	0	2014-11-16 02:18:44 UTC+0000	

Figure 15: An excerpt of Symform processes recovered using the *pslist* Function of Volatility.

When we accessed Symform using the client applications, we were able to carve the image icons used by the client applications as well as files of forensic interest, such as `symformsync.log`, `node.config`, and the *metadata* database from the RAM captures. We could also recover the thumbnail images, script files, HTML documents, cache files, and other web browser files used by the web application after accessing the Symform web application. In all the investigated VMs, we could recover sample files from the RAM captures intact.

Manual analysis of the RAM captures of the client applications' file synchronisation VMs (1.4.2, 1.4.3, 2.3, 2.4, 3.3, and 3.4) revealed copies of the files of forensic interest in the memory space of `symformsync.exe` on Windows machine, `symformsync` on Ubuntu machine, and `symform` on Mac OS machine in plain text; Figure 16 and Figure 17 show examples of the remnants of the *node.config* and *metadata* database, respectively. This could prove useful to forensic practitioners when seeking to determine the origin of

the texts in the absence of the original files. Our findings suggested that there are more than one way to recover the filename and path references for synced files from the *symformsync.log* in the RAM, for example, by searching for the terms *uploading* and *downloading*. Moreover, the terms '*userName=*' and *creationversion* could be used to locate remnants of the `node.config` and *metadata* database respectively during future searches. When we used a browser to download the synced files, we were able to recover copies of the download links from the RAM (see Figure 18) by searching for `content.symform.com`.

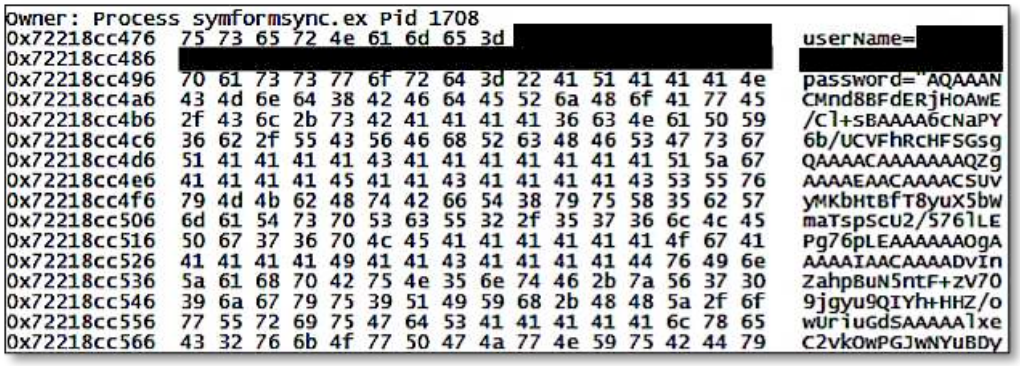


Figure 16: Remnants of node.config located within the memory space of `symformsync.exe`.

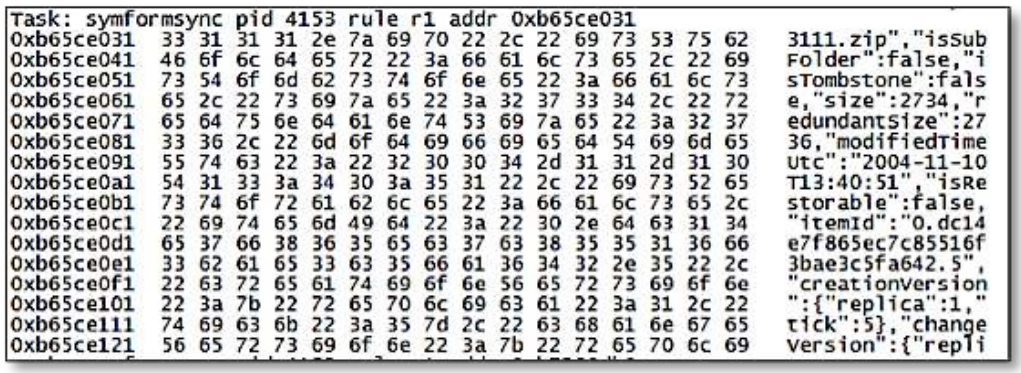


Figure 17: Remnants of *metadata* database located within the memory space of `symformsync`.

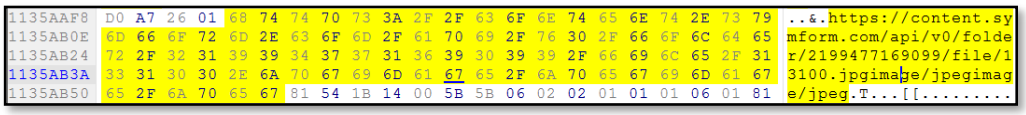


Figure 18: A file download link recovered from the RAM of Mozilla Firefox VM.

A search for Enron-related keywords (e.g., *Enron* and *Pensive Parakeet*) in the RAM of all the file synchronisation VMs (1.1.2 IE, 1.2.2 MF, 1.3.2 GC, 1.4.2, 1.4.3, 2.3, 2.4, 3.3, and 3.4) resulted in the recovery of the complete text of the sample files. Although the login credentials were encrypted, when we used the web browsers to access the Symform web application, the username and password were found prefixed with the terms *session.emails* and *session.password* respectively in the RAM captures; Figure 19 depicts an example. The login email and password for the RDM could be recovered from the RAM of the Ubuntu's access and file synchronisation VMs (2.2, 2.3, and 2.4) in plaintext (see Figure 20) by searching for the terms '*"email":*' and '*"password":*'. When the credentials were saved in the Keychain (the password manager of Mac OS), we were able to recover the master key by using the *keychaindump* Function of Volatility. The master key recovered was then used to decrypt the credential details using `chainbreaker.py` script, as shown in Figure 21.

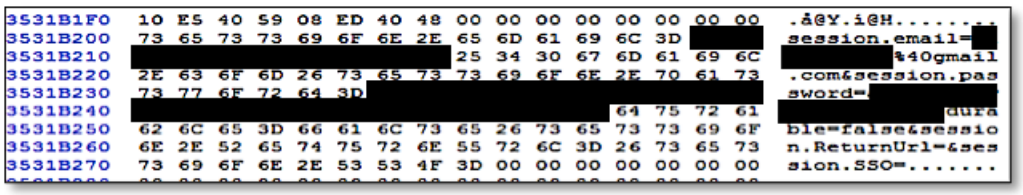


Figure 19: Symform login credentials recovered from the RAM of Google Chrome VM.

Undertaking file deletion using the web application resulted in the recovery of the deletion message "Are you sure you want to delete [Filename] from your account? Files will be saved for up to 7 days for recovery?". The file deletion could also be discerned from the presence of the link `https://control.symform.com/api/v0/folder/[FolderglobalID]/file/[Filename]` prefixed with the term *delete* in the RAM of Mac OS. We remark that the findings are dependent on the RAM size and user activities undertaken prior to the forensic examination.

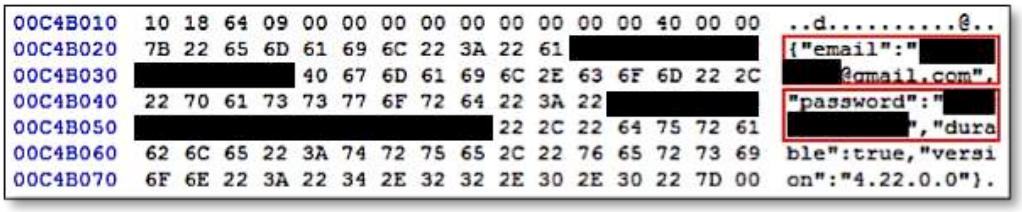


Figure 20: Symform login credentials recovered from RAM.

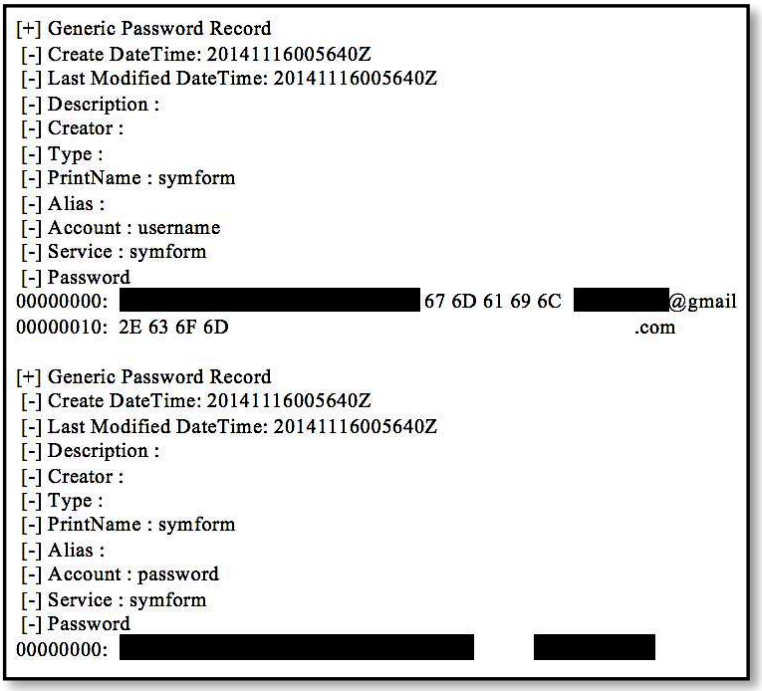


Figure 21: An excerpt of `chainbreaker.py` output.

When we searched for the term *Symform* in the swap files (also known as *pagefile.sys* on Windows [63]) of all the file synchronisation VMs (1.1.2 IE, 1.2.2 MF, 1.3.2 GC, 1.4.2,1.4.3, 2.3, 2.4, 3.3, and 3.4), we could only recover
685 *filename/path* references for the synced files and client application files (when accessed using the client applications). Although the findings from swap files were not as conclusive as those presented for the RAM analyses, the presence of the *filename/path* references in the swap files could prove useful to indicate recent Symform usage.

4.6. Unallocated space

Unallocated space is a potential source of information in an investigation, such as intact files as well as filename and path references that were created and deleted by the user or the system [21, 22]. Similar to the RAM analysis, in our examination of the unallocated client applications' file synchronisation VMs (1.4.2, 1.4.3, 2.3, 2.4, 3.3, and 3.4), we identified that the files of forensic interest such as `symformsync.log`, `node.config`, `synced files`, as well as the *metadata* database could be recovered from the unallocated spaces intact. Moreover, we were able to recover copies of the image icons and files of relevance (e.g., script files, HTML documents) used by the client application, RDM, and web application from the unallocated spaces; indicative of Symform usage. The presence of the data remnants aforementioned in the Delete-VM (1.4.3.1, 2.3.1, 3.3.1) and Uninstall-VM (1.4.2.1, 2.4.1, 3.4.1) reinforced that unallocated partition is an important source for recovering deleted Symform or synced files.

4.7. Windows system files

In this section, we present the Symform artefacts located within the registry, prefetch and link files of Windows 8.1.

4.7.1. Registry files

Windows registry provides a rich source of information associated with installed programs [64]. Although five hives could be seen in the registry, only HKEY_USERS (HKU) and HKEY_LOCAL_MACHINE (HKLM) hives are tangibly real, since the remaining are merely symbolic links to the two master keys [65]. An analysis of the registry of the Install-VM (1.4) revealed that the installation of the Symform client application would result in the addition of approximately 82 registry keys. We could detect the installation from the presence of entries referencing Symform executable files, the Symform version installed, the installation paths, Symform URLs, the date it was installed, or other options in the following registry keys:

- `HKLM\SOFTWARE\Microsoft\Windows\CurrentVersion\Installer\UserData\S-1-5-18\Products\[Product GUID]\InstallProperties`
- `HKLM\SOFTWARE\Microsoft\Windows\CurrentVersion\Uninstall\{[Product GUID]}`

In addition to the aforementioned registry keys, we located descriptions and full path references for Symform services (e.g., symformsync, symformupdater, and symformcontrib) in the following registry subkeys:

- HKLM\SYSTEM\ControlSet001\Services\[Symform service name]
- HKLM\SYSTEM\CurrentControlSet\Services\[Symform service name]

While using the Symform client application, we observed that six sub-branches for Symform setup, contribution, and status services were created in the Windows Routing and Remote Access service (RRAS) registry keys listed below. According to [66], the keys are used to enable file tracing for diagnosing network problems (relating to the Symform client application in this case). The keys remained in the registry even after the Symform client application was uninstalled.

- HKLM\SOFTWARE\Microsoft\Tracing\Symformcontrib_RASAPI32
- HKLM\SOFTWARE\Microsoft\Tracing\Symformcontrib_RASMANICS
- HKLM\SOFTWARE\Microsoft\Tracing\Symformsetup_RASAPI32
- HKLM\SOFTWARE\Microsoft\Tracing\Symformsetup_RASMANICS
- HKLM\SOFTWARE\Microsoft\Tracing\Symformstatus_RASAPI32
- HKLM\SOFTWARE\Microsoft\Tracing\Symformcontrib_RASMANICS

Each time an application is started, Windows automatically extracts the application name from the version resource of the executable file and stores it in the *MuiCache* registry key for later use [67]. When the Symform client application was started up, we located entries referencing Symform executable files in the following *MuiCache* keys:

- HKU\$< SID >$_Classes\Local Settings\MuiCache
- HKU\S-1-5-21\Software\Classes\Local Settings\MuiCache

Similar to any other Windows application, when we configured Symform to run automatically whenever Windows starts, we located entries referencing *Symform* under `Software\Microsoft\Windows\CurrentVersion\Run` registry key (Figure 22 depicts an example). Other evidence indicating the use of the Symform client application include the presence of entries referencing `%Desktop% \SymformNodeNew.exe (1)` as well as the time when the client application was last executed in `Software\Microsoft\Windows\CurrentVersion\Explorer\UserAssist` (which holds information about the `.EXE` files and links that a user opens frequently [68]).

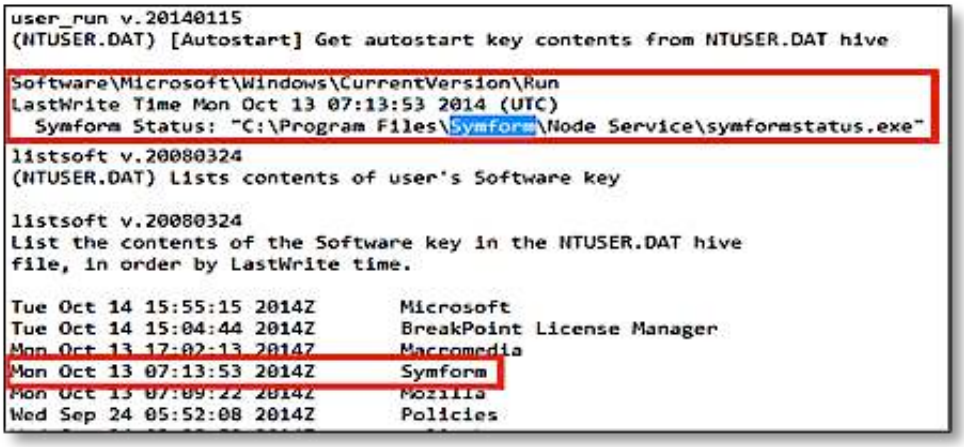


Figure 22: Symform entry located under `Software\Microsoft\Windows\CurrentVersion\Run`.

The *TypedURLs* key contains a listing of 25 recent URLs (or file path) typed in the Internet Explorer or Windows Explorer address bar [69]. When we used Internet Explorer to access Symform account, we could locate references to Symform URLs and the accessed times under `Software\Microsoft\Internet Explorer\TypedURLs` and `Software\Microsoft\Internet Explorer\TypedURLsTime` registry keys respectively, Figure 23 shows an example. It is to the best of the authors' knowledge that none of the remaining browsers utilise the registry in the way that Internet Explorer does.

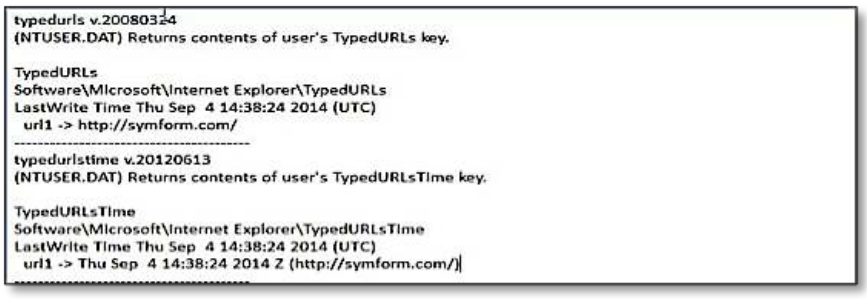


Figure 23: Symform URLs located under `Software\Microsoft\Internet Explorer\TypedURLs` and `\Software\Microsoft\Internet Explorer\TypedURLsTime`.

Another registry key of forensic interest is the `Software\Microsoft\Windows\CurrentVersion\Explorer\ComDlg32`. According to [70], the *CIDSizeMRU* (MRU is the abbreviation for Most-Recently-Used) subkey maintains a list of recently used applications, the *OpenSaveMRU* registry subkey records list of files that have been opened or saved within a Windows shell dialog box, and the *LastVisitedMRU* subkey is responsible for tracking specific executable files used by an application to open the files documented in the *LastVisitedMRU* subkey. When we downloaded the sample files, we identified that there were various entries making reference to Symform or the browser's executable file (when downloaded using a browser) in the aforementioned registry subkeys, which included *filenames* for the downloaded files and references to the last accessed times (see Figure 24).

The *RecentDocs* key corresponds to `%Recent%\` (My Recent Documents), which maintains a list of local or network files recently executed or opened through Windows Explorer [71]. Undertaking a download of the sample files resulted in the creation of entries making reference to filenames and file extensions for the downloaded files as well as the last written times in `Software\Microsoft\Windows\CurrentVersion\Explorer\RecentDocs` (see Figure 25). We were also able to locate entries referencing the HTML document of the Symform web application (namely `Symform Web App.htm`) in the *RecentDocs* key after we had accessed the Symform account using a browser.

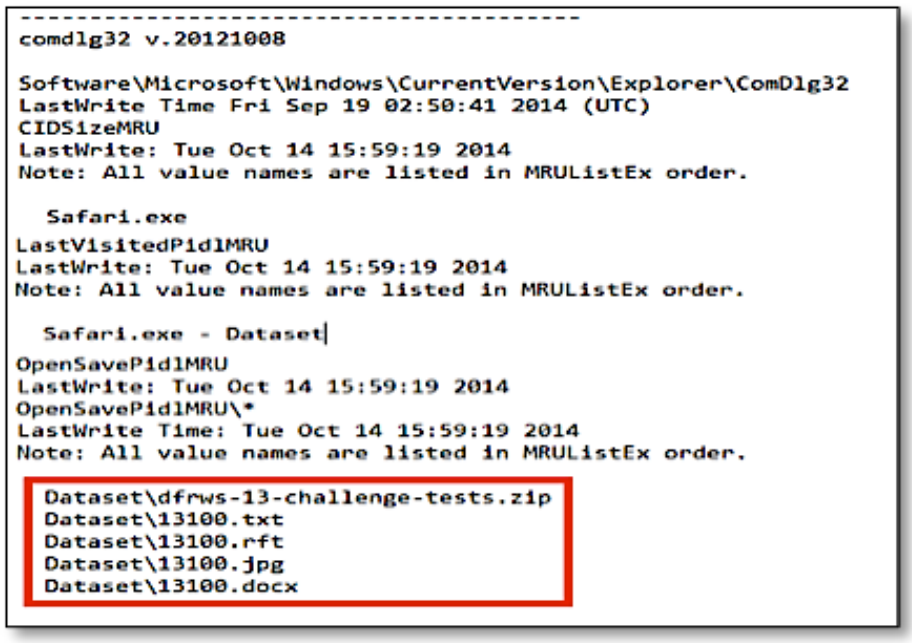


Figure 24: File download information located in `Software\Microsoft\Windows\CurrentVersion\Explorer\ComDlg32`.

4.7.2. Prefetch files

A prefetch file contains information about a loaded application on Windows (e.g., executable filename, path, associated dlls, number of times an application has been loaded, last run time, and other associated timestamps). An examination of the prefetch files in `%SystemRoot% \Prefetch` of the Install-VM (1.4) identified that the installation would result in the creation of Symform prefetch files such as `SYMFORMSETUP.EXE.pf`, `SYMFORMNODENEW.EXE.pf`, and `SYMFORMUPDATER.EXE.pf`. When we performed file synchronisation, we could observe the prefetch files namely `SYMFORMCONTRIB.EXE.pf` (for the contribution service), `SYMFORMSTATUS.EXE.pf`, and `SYMFORMSYNC.EXE.pf` in the file synchronisation VMs (1.4.2 and 1.4.3). However, we could not locate any prefetch entry relating to the synced files. We determined that the Symform prefetch files remained in the hard drive even after uninstalling the client application.

Figure 25: Recently opened documents located in `Software\Microsoft\Windows\CurrentVersion\Explorer\RecentDocs`.

4.7.3. Link files

Link (`.lnk`) files are shortcut metadata files used by Windows to maintain a list of linked paths relating to a file (commonly the paths where the original files are located), associated timestamps (create, write, and last accessed times), and file sizes (original and modified), which could be used to identify the origin of a file [72]. Analysing the link files of the client application's file synchronisation VMs (1.4.2 and 1.4.3), we located two link files namely `Symform Setting.lnk` and `Symform Status.lnk` for `%Program Files% \Symform\Node Service\symformsetup.exe` and `%Program Files% \Symform\Node Service\symformstatus.exe`, respectively in `%ProgramData% \Microsoft\Windows\Start Menu\Programs\Symform\`. Of all the VMs investigated, we were only able to locate link files for the sample files under `%AppData% \Roaming \Microsoft\Windows\Recent\` of the Mozilla Firefox Download-VM (1.2.2).

5. Symform analysis on mobile devices

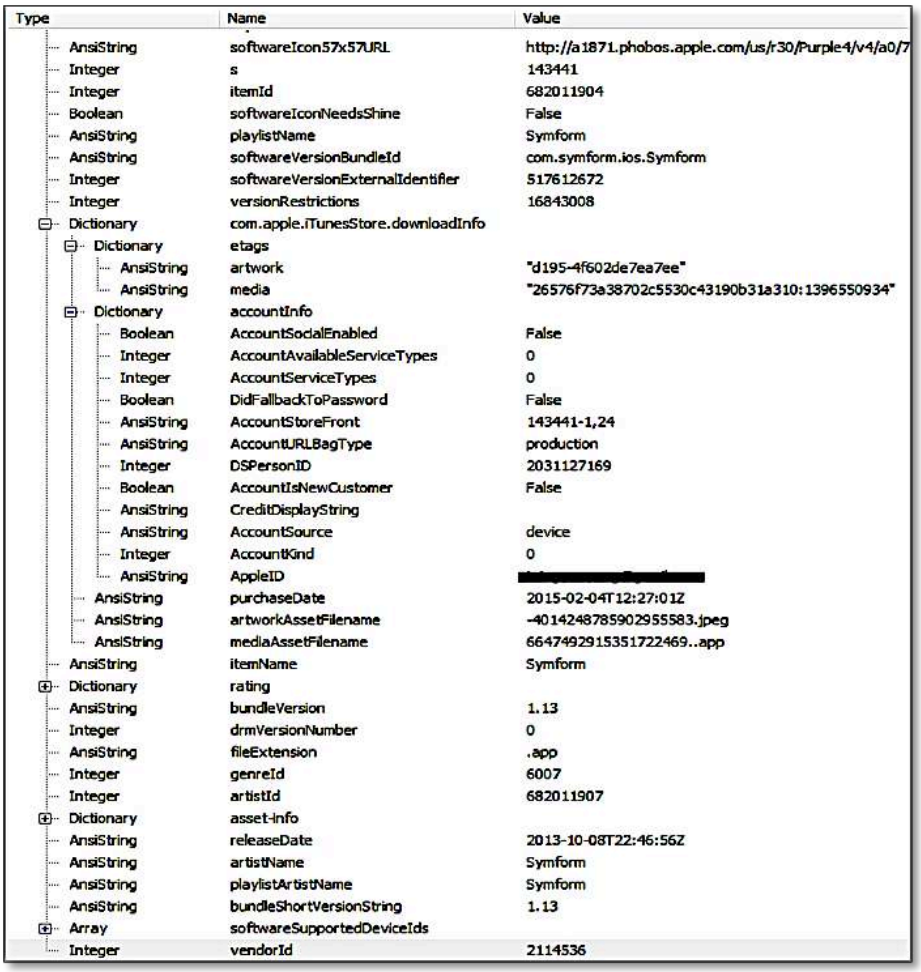
In this section, we present the findings of our analysis on iPhone 4 running iOS 7.1.2 and an HTC One X running Android KitKat 4.4.

5.1. Symform analysis on iOS 7.1.2

Examination of the directory listing identified that the Symform iOS app installation could be discerned from the presence of the `/private/var/mobile/Applications/[Unique SHA-1 identifier for the Symform iOS app]/Symform.app` application folder. The `/private/var/mobile/Applications/[Unique SHA-1 identifier for the Symform iOS app]/iTunesMetadata.plist` maintains a list of mobile-specific metadata associated with the Symform app such as the Apple ID used to purchase the app, the purchase date, the Symform version installed and other information, as detailed in Figure 26.

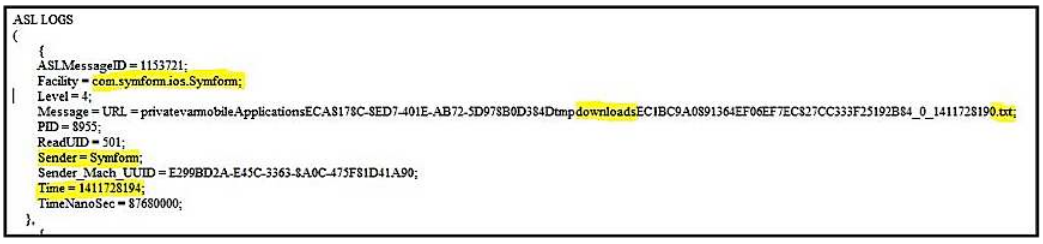
The `Cache.db` (see Section 4.1.3) for the Symform iOS app could be located in `/private/var/mobile/Applications/[Unique SHA-1 identifier for the Symform iOS app]/Library/Caches/com.symform.ios.Symform/`. When we viewed the sample files, we located copies of the files in `/private/var/mobile/Applications/[Unique SHA-1 identifier for the Symform iOS app]/private/var/mobile/Applications/[Unique SHA-1 identifier]/tmp/downloads/` intact, which included the file formats and viewing timestamps.

Whilst viewing the synced files in the app, we observed that Symform iOS application (Version 1.13) offers an option to upload logs. When this option is enabled, a copy of the `symformcloudcachelogs.log` (see Section 4.2.3) will be emailed to the account owner. In addition, we could detect the trace of Symform usage from the `/private/var/log/DiagnosticMessages/YYYY.MM.DD.asl` log of iOS. Other than the Kernel and system events (similar to those discussed in Section 4.2.3), we could recover the file download URLs as well as the timestamp information from the ASL logs (see Figure 27). Neither Symform-related folder nor files remained after the uninstallation of the Symform iOS app.



Type	Name	Value
AnsiString	softwareIcon57x57URL	http://a1871.phobos.apple.com/us/r30/Purple4/v4/a0/7
Integer	s	143441
Integer	itemId	682011904
Boolean	softwareIconNeedsShine	False
AnsiString	playlistName	Symform
AnsiString	softwareVersionBundleId	com.symform.ios.Symform
Integer	softwareVersionExternalIdentifier	517612672
Integer	versionRestrictions	16843008
Dictionary	com.apple.iTunesStore.downloadInfo	
Dictionary	etags	
AnsiString	artwork	"d195-4f602de7ea7ee"
AnsiString	media	"26576f73a38702c5530c43190b31a310:1396550934"
Dictionary	accountInfo	
Boolean	AccountSocialEnabled	False
Integer	AccountAvailableServiceTypes	0
Integer	AccountServiceTypes	0
Boolean	DidFallbackToPassword	False
AnsiString	AccountStoreFront	143441-1,24
AnsiString	AccountURLBagType	production
Integer	DSPersonID	2031127169
Boolean	AccountIsNewCustomer	False
AnsiString	CreditDisplayString	
AnsiString	AccountSource	device
Integer	AccountKind	0
AnsiString	AppleID	[redacted]
AnsiString	purchaseDate	2015-02-04T12:27:01Z
AnsiString	artworkAssetFilename	-4014248785902955583.jpeg
AnsiString	mediaAssetFilename	6647492915351722469..app
AnsiString	itemName	Symform
Dictionary	rating	
AnsiString	bundleVersion	1.13
Integer	drmVersionNumber	0
AnsiString	fileExtension	.app
Integer	genreId	6007
Integer	artistId	682011907
Dictionary	asset-info	
AnsiString	releaseDate	2013-10-08T22:46:56Z
AnsiString	artistName	Symform
AnsiString	playlistArtistName	Symform
AnsiString	bundleShortVersionString	1.13
Array	softwareSupportedDeviceIds	
Integer	vendorId	2114536

Figure 26: Content of `iTunesMetadata.plist`.



```
ASL LOGS
(
    {
    ASLMessageID = 1153721;
    Facility = com.symform.ios.Symform;
    Level = 4;
    Message = URL = privatevarmobileApplicationsECA8178C-8ED7-401E-AB72-5D978B0D384Dtmpdownloads EC1BC9A0891364EF06EF7EC827CC333F25192B84_0_1411728190.txt;
    PID = 8955;
    ReadUID = 501;
    Sender = Symform;
    Sender_Mach_UUID = E299BD2A-E45C-3363-8A0C-475F81D41A90;
    Time = 1411728194;
    TimeNanoSec = 87680000;
  },
```

Figure 27: An example of ASL log containing file download information of the Symform iOS app.

5.2. Symform analysis on Android KitKat 4.4

The installation of the Symform Android app resulted in the creation of `/data/data/com.symform.android.symform` folder which has five subfolders, namely `app_webview`, `cache`, `files`, `lib`, and `shared_prefs`. The file of particular interest is `/data/data/com.symform.android.symform/shared_prefs/SymformPrefs.xml` file, which stores the username (email address) and encrypted password used to login the app. Meanwhile, the folder of interest is the `/data/data/com.symform.android.symform/files/downloads` folder, which holds a list of files downloaded to the device. No Symform-related folder or file remained after uninstalling the Android app.

6. Network analysis

When accessing Symform using a web browser, we established the initial session with the main web server (`www.symform.com` with IP address `104.130.154.151` in our research) and then to the login page (`control.symform.com` with IP address `173.193.191.132` in our research) over port 80 (HTTP). We observed the network traffic only on port 443 (HTTPS) as soon as sign-in took place, and Starfield Technologies [73] issued the certificates. Also occurring was a session with Google Analytic services (e.g., IP addresses `74.125.*.*` in our research) during sign-in. The next servers accessed were the AmazonAWS servers (e.g., IP addresses `54.231.*.*`) which host Amazon Web Services (EC2) with additional information referencing Symform. An examination of the client application's network traffic revealed similar observations, but we did not observe any session established with the Symform web server.

When we downloaded the sample files using a web browser, we located URLs that made reference to `content.symform.com` within the TCP stream. When file synchronisation was undertaken using the client application, we identified the UDP as the carrying protocol and we could recover the IP addresses of the peer nodes. However, the port numbers appeared to be random, thereby, making the ports unpredictable. Although the files were encrypted using 256-bit AES encryption, we were able to locate remnants of the HTTP requests for the backup file fragments including the requests IDs in the UDP stream (see Figure 28). The corresponding timestamp information recorded alongside the relevant IP addresses could be used to facilitate re-constructing of the user activity timeline.

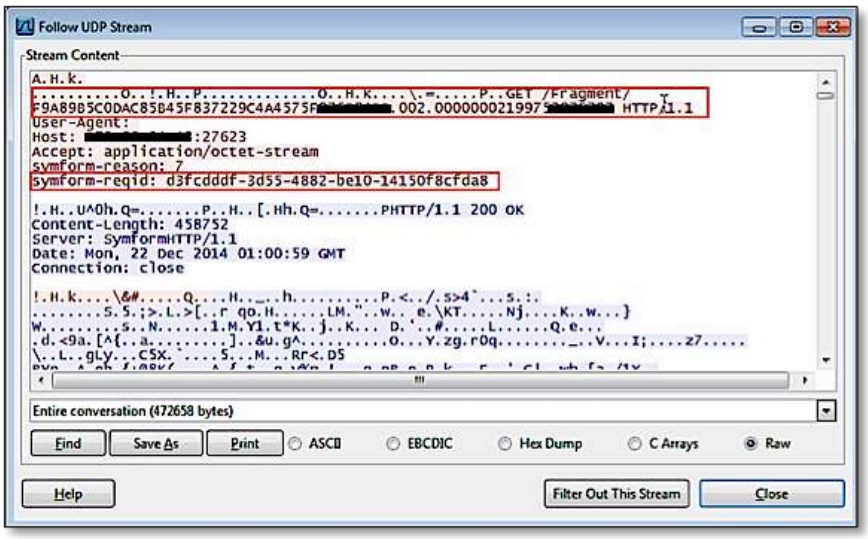


Figure 28: An excerpt of UDP stream containing remnants of the HTTP request for a backup file fragment.

Rebuilding the network captures of Symform web application using *Network Miner*, we recovered the HTML documents, Javascripts, CSS files, and image files from the unencrypted traffic. Of all the platforms investigated, we were able to recover certificates used to authenticate the HTTPS sessions.

7. Concluding Remarks

The increasing popularity of cloud computing among individual users and organisations, as well as criminals resulted in the need for forensic investigators to have a contemporary understanding of the artefacts that may be left behind by different types of cloud storage system on a client device (e.g., personal computers and mobile devices). In this paper, we described the potential terrestrial artefacts that may be left behind on a client device running Window 8.1, Ubuntu 14.04 LTS, Mac OS X Mavericks 10.9.5, iOS 7.1.2 and Android KitKat 4.4 after the use of Symform (a cooperative storage cloud service).

Our timestamp analysis indicated that the MD5 and SHA1 hash values did not change during the process of uploading, storage, and downloading files from Symform. Examinations of the directory listings revealed that the Symform client application maintains a list of log files for the main

services under %Program Files% \Symform\Node Service\logs\ on Windows 8.1, /var/log/symform/ on Ubuntu, as well as /Library/Application Support/Symform/bin/ and /private/var/logs/Symform/ on Mac OS. These logs could be useful in recovering history of Symform usage. This was not the case for machines and devices running Ubuntu, Mac OS, and Android (i.e. we could not recover any system log that could be used to identify synced files/folders).

The node.config file (located under %Program Files% \Symform\Node Service\ on Windows 8.1, /var/lib/symform/ on Ubuntu, and /private/var/lib/ on Mac OS) is another potential evidence source, which contains node-specific configuration details for the file synchronisation and contribution services. In all the operating systems investigated, two hidden subfolders namely .symform and .symform-store were created in the sync/backup folders to store the synced file caches. The *metadata* database located within the .symform subfolder would be of particular interest to forensic practitioners when seeking to recover the synced file history of the sync folder. The deleted files could be potentially located in the %$Recycle.Bin% \SID folder on Windows 8.1, /home/[User Profile]/.local/share/Trash/files folder on Ubuntu, and /Users/[User profile]/.Trash folder on Mac OS when not emptied. The filename and location references, located as part of our research, may facilitate the identification of other sources of evidence and result in timely preservation of the evidence.

When we accessed Symform using a web browser, we were able to locate URLs referencing www.symform.com (Symform webpage), control.symform.com (Symform login link), and content.symform.com/api/v0/folder/[Folder global ID]/[Filename] (Symform file download link) alongside the associated timestamps and the view counts in the web browsing information. Meanwhile, accessing the RDM would leave URLs referencing 127.0.0.1:59234 in the web browsing history. The presence of the downloaded files in the web browsing caches would create potential for alternative methods for recovery of the downloaded files.

Undertaking data carving of the unallocated partitions and memory files confirmed that we could recover the files of forensic interest from unallocated partitions and memory files. When we used a browser to access Symform web application, the username and password could be potentially recovered from the RAM. Analysing the system processes using the *'pslist'* function of Volatility, we could discern the process names from *symformweb*, *symformsync*,

and *symformcontrib* on Windows and Ubuntu OS, and *Symform* on Mac OS. However, it is noteworthy that we captured the RAM immediately after performing each experiment, but prior to a system shutdown in our research. Thus, the data remnants identified in this research do not represent those recoverable in a typical "real world" circumstance, unless capturing the RAM on a suspect system "in real life" immediately after the action but prior to a shutdown.

In our investigations on the mobile applications, we forensically recovered copies of the viewed files from `/private/var/mobile/Applications/[Unique SHA-1 identifier]/tmp/downloads/` on iOS and `/data/data/com.symform.android.symform/files/downloads/` on Android devices. In our examinations of the network captures, we determined that most of the data from the application layer were encrypted, but the IP addresses of the peer nodes could be located from the UDP traffic. When file synchronisation took place using the client application, we were able to forensically recover the request IDs for the backup file fragments from the UDP stream. The corresponding timestamp information recorded alongside the relevant IP addresses is, particularly, useful for timeline analysis. The summary of findings from the mobile and computer devices investigated in this research study is presented in tables 6 and 7.

To keep pace with technological advances, future work would include extending this research to other popular cooperative storage cloud services (e.g., Storj), as well as developing a forensically sound tool to automate collection of artefacts common to popular cooperative storage cloud services.

Table 6: Summary (R =Recoverable, P = Possibly Recoverable, N = Not Recoverable).

Platform	Source of Evidence	Data artefacts found		
		Installation/ uninstallation information	**Username/ Email address**	**Password**
Windows 8.1(client and web applications)	**Directory listings/ Stored files**	R	R	R
	Registry files	R	N	N
	Log files	R	R	N
	Web browser files	P, client app download link	P	R, only saved credentials in the web browser
	Prefetch	R, prefetch files for the executable files	N	N
	Thumbcache files	R, client app icons	N	N
	Link files	R	N	N
	Fileslack	N	N	N
	RAM	P	P	P, only web app login password
	Pagefile.sys	P	P	N
	Unallocated space	P	P	N
Ubuntu 14.04 LTS	**Directory listings/ Stored files**	R	R	R, login password from node.config
	Log files	R	R	N
	Web browser files (only RDM)	P, client app download link	P	N
	Thumbcache files	N	N	N
	RAM	P	P	P, RDM's login password
	Swap partition	P	P	N
	Unallocated partition	P	P	N
Mac OS X Mavericks 10.9.5	**Directory listings/ Stored files**	R	R	R, login password from node.config
	Log files	R	R	N
	Web browser files	P, client app download link	P	N
	Thumbcache files	N	N	N
	RAM	P	P	P, RDM's login password
	Swap partition	P	P	N
	Unallocated partition	P	P	N
iOS 7.1.2	**Directory listings/ Stored files**	R	R	N
	Log files	P	N	N
Android Kitkat 4.4	**Directory listings/ Stored files**	R	N	R, login password from SymformPrefs.xml
Network traffic		R	N	N

Table 7: Summary (R =Recoverable, P = Possibly Recoverable, N = Not Recoverable).

Platform	Source of Evidence	Data artefacts found		
		Symform log or configuration files/path references	**Symform URLs**	**Enron sample files/path references**
Windows 8.1(client and web applications)	**Directory listings/ Stored files**	R, login password for the client app from node.config	R	R
	Registry files	N	R	P
	Log files	R, copies of node.config file in symformsync.log	R	R
	Web browser files	N	R	P
	Prefetch	N	N	N
	Thumbcache files	N	N	R, only the synced Enron image
	Link files	N	N	N
	Fileslack	N	N	N
	RAM	P	P	P
	Pagefile.sys	P	P	P
	Unallocated space	P	P	P
Ubuntu 14.04 LTS	**Directory listings/ Stored files**	R	R	R
	Log files	R, copies of node.config file in symformsync.log	R	R
	Web browser files (only RDM)	N	R	N
	Thumbcache files	N	N	N
	RAM	P	P	P
	Swap partition	P	P	P
	Unallocated partition	P	P	P
Mac OS X Mavericks 10.9.5	**Directory listings/ Stored files**	R	R	R
	Log files	R, copies of node.config file in symformsync.log	R	R
	Web browser files	N	R	N
	Thumbcache files	N	N	N
	RAM	P	P	P
	Swap partition	P	P	P
	Unallocated partition	P	P	P
iOS 7.1.2	**Directory listings/ Stored files**	R	N	R
	Log files	N	P, only in the ASL log	N
Android Kitkat 4.4	**Directory listings/ Stored files**	N	N	R
Network traffic		N	R, IP addresses of the peer nodes	N

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