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Investigating Social Networking applications on smartphones detecting Facebook, Twitter, LinkedIn and Google+ artefacts on Android and iOS platforms

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The rapid growth in usage and application of Social Networking (SN) platforms make them a potential target by cyber criminals to conduct malicious activities such as identity theft, piracy, illegal trading, sexual harassment, cyber stalking and cyber terrorism. Many SN platforms are extending their services to mobile platforms, making them an important source of evidence in cyber investigation cases. Therefore, understanding the types of potential evidence of users' SN activities available on mobile devices is crucial to forensic investigation and research. In this paper, we examine four popular SN applications: Facebook, Twitter, LinkedIn and Google+, on Android and iOS platforms, to detect remnants of users' activities that are of forensic interest. We detect a variety of artefacts (e.g. usernames, passwords, login information, personal information, uploaded posts, exchanged messages and uploaded comments from SN applications) that could facilitate a criminal investigation.

Keywords: digital forensics; social networking application forensics; mobile app forensics; mobile device forensics; Android investigation; iOS investigation; Facebook forensics; Twitter forensics; LinkedIn forensics; Google+ forensics

1. Introduction

Social network applications allow individuals to construct a public or semi-public profile within a bounded system, articulate a list of other users with whom they share a connection, and view and traverse their list of connections and those made by others within the system¹. Currently, Facebook is the most popular SN platform with around 1.06 billion active users² followed by Twitter, LinkedIn and Google+. These platforms provide users with features such as email, blogging, instant messaging and photo sharing³. Various types of personal information are shared on SN platforms such as name, date of birth, photos, email addresses, phone numbers and group affiliations, which could provide crucial information during a crime investigation⁴. SN sites provide customised features and interactions according to each user's personal preferences, social graph, and the digital mapping of people's real-world social connections.

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Smartphones, an increasingly popular way of accessing SN services on the go, store a wealth of personal information. For example, as many as 40% of SN users reportedly access SN applications through their mobile devices⁵, and so are cyber criminals⁶. Not surprisingly, smartphones have been widely targeted by cybercriminals such as malware designed to steal users' private data⁷⁻⁹. Rapid changes in mobile device technologies and the wide range of mobile operating platforms and devices compound the challenges in a forensic investigation¹⁰. At the time of research, Android with 51.5% market share and Apple's iOS with 42.4% market share are the most popular mobile platforms¹¹. Therefore, it is important for law enforcement and the forensic communities to keep pace with technologies¹²⁻¹⁴.

In addition to a criminal investigation, forensic investigation of SN applications may also be required in a civil litigation or a corporate disciplinary investigation of employees suspected of breaching company policies^{15,16}. However, there do not appear to be any commonly used guidelines specifically related to investigation of SN mobile applications^{6,17}.

1.1. Related Work

There are three methods for acquiring data from a smartphone: manual acquisition, logical acquisition and physical acquisition¹⁸. During manual acquisition, data are retrieved by copying a log of the actions taken on the device¹⁹ and copying existing application data²⁰. Casey²¹ describes logical acquisition as a bitwise copy of files and directories that contains timestamp and location of resident files within the filesystem of the device. Logical acquisition is classified into the following categories: copying files and folders, partition imaging, content provider and recovery mode data collection²²⁻²⁴. In the physical acquisition, a bitwise copy of the internal memory of the device would be acquired, which normally includes deleted data.

Physical acquisition of Android devices is generally performed using dd, JTAG, physical extraction and DMD. Logical acquisition of Android devices can be conducted by either using mobile forensic tools such as Cellebrite UFED or by booting into recovery mode. Lessard and Kessler²⁵ performed physical acquisition by gaining superuser access and using dd on an ADB shell to retrieve images of each mtd file present in the '/dev/mtd' directory, and logical acquisition using Cellebrite UFED to extract data from the '/data/data' directory of a HTC Hero running Android 1.5. Vidas *et al.*²⁴ used the booting into recovery mode method to perform logical acquisition. JTAG and physical extraction methods are useful when performing logical acquisition is not possible, while booting into and collecting data in the recovery mode can be used when the device is powered off and the analyst wishes to avoid powering on the device. Sylve *et al.*²⁶ used the DMD method to perform physical acquisition of a rooted HTC Android device. Son *et al.*²³ utilised JTAG and recovery mode data collection methods to perform physical and logical acquisition of rooted Samsung devices running Android platforms, and concluded that both methods to acquire similar data. Do *et al.*²⁷ proposed an adversary model for Android covert data exfiltration which was then used to build a mobile data exfiltration technique (MDET). In this model, common communication mediums found on almost all mobile devices are used to obtain sensitive data from Android devices in a covert manner. The authors also developed two proof-of-concepts that use SMS and audio to exfiltrate data from Android devices.

With older iOS devices, physical acquisition can be conducted using the dd method, and logical acquisition is performed using Apple's iTunes. Zdziarski²⁸ acquired a

physical image of an iPhone 3G by booting it with a recovery toolkit called iLibrary+version 1.6, which enables the acquisition of a bitwise copy of the memory image using the dd command. Hoog and Gaffaney²⁹ performed physical and logical acquisitions on an iPhone 3GS (2.2 firmware) using iTunes backup and Zdziarski's physical dd method and concluded that Zdziarski's method is more accurate in terms of ease of installation and integrity of acquired data. Morrissey and Campbell³⁰ also used the iTunes backup to perform logical acquisition on iPhone 2G and 3GS and recovered artefacts of call logs, address book, cookies, logs, geolocation data, web browsing, SMS/MMS, multimedia and application data. Bader and Baggili³¹ used the iTunes backup to perform a logical acquisition on an iPhone 3GS and classified the collected files into three categories: plist files, which store data in plaintext format; mddata files, which store data in a raw binary format; and mdfinfo files, which store encoded meta-data of the corresponding mddata files. Bader and Baggili³¹ claimed that evidential data from iPhones were mainly obtained using logical acquisition as they are more compliant to forensic standards (NIST, 2014). However, they also noted several limitations in using logical acquisition such as limitation of interaction with iTunes versions prior to 8.2 for iPhone versions 3GS or higher.

Proffitt³² stated that frequent changes in security mechanisms employed by iOS devices can make the task of acquiring a forensically sound image more challenging. For instance, the employed security methods on iOS version 3 and iOS version 6 are so different that methods used to acquire an image from iOS 3 do not work on iOS 6. For example in another related work, Al Mutawa *et al.*³³ extracted a database file from the Facebook application on an iOS 4 device, which was not found on iOS 6 devices³⁴. Ariffin *et al.*³⁵ also explained the complexity of retrieving unallocated and encrypted data from iOS devices and presented an acquisition method for recovering deleted image files from the iOS journaling system in iPhone 3GS and 4, which may not work for newer iOS devices.

Jung *et al.*³⁶ investigated Cyworld, Me2Day, Yozm, NateOn UC, KakaoTalk, MyPeople, Twitter and Facebook applications for iOS version 3.x and 4.x, and using the logical acquisition technique, they recovered multimedia images, user-driven social media attributes and geolocation data. In another work, Said *et al.*³⁷ investigated Facebook and Twitter apps on iPhone 3GS, BlackBerry Bold and Samsung Omnia II and extracted friends lists and birthday notifications. Tso *et al.*³⁸ analysed Facebook, WhatsApp Messenger, Skype, Windows Live Messenger and Viber applications on an iPhone 4 running iOS version 4.3.5 and extracted users' personal data, messages, contact lists and posts from backup folders. Al Mutawa *et al.*³³ investigated Facebook, Twitter and MySpace applications on an iPhone 4, BlackBerry Torch 9800 and Samsung GT-i9000 Galaxy S and extracted users' personal data, uploaded photos and posted comments. Quick and Choo³⁹⁻⁴¹ recovered users' personal data, login information, downloaded files, uploaded files and deleted files of Dropbox, SkyDrive and GoogleDrive cloud client applications from an iPhone 3G running iOS 4.2.1. Anglano⁴² extracted a variety of artefacts such as the contact list, exchanged messages, deleted contacts, and deleted messages of the WhatsApp instant messaging application from a virtualised Android device on YouWave.

To the best of our knowledge, there are very limited works on the investigation of SN platforms on mobile devices. To contribute to this framework, we also adopt a framework based on Refs.⁴³ and⁴⁴ to guide our investigation of the SN applications, namely Facebook, Twitter, LinkedIn and Google+ applications on both Android and iOS platforms.

1.2. Research questions and contributions

To address the aforementioned gap, the following research questions will be answered in this paper.

- (1) What artefacts of forensic value remain on Android internal memory and internal storage from using the Facebook, Twitter, LinkedIn and Google+ applications?
- (2) What artefacts of forensic value reside on iOS internal storage from using the Facebook, Twitter, LinkedIn and Google+ applications?
- (3) What network traffic artefacts can be detected when users are using the Facebook, Twitter, LinkedIn and Google+ applications on Android and iOS platforms?

The main contribution of this research is a systematic way of recovering artefacts of users' activities within SN applications and examining their forensic values. This paper may serve as a guideline for forensic practitioners during investigation of SN platforms including Facebook, Twitter, LinkedIn and Google+, on both Android and iOS platforms.

1.3. Investigation framework

Using ad hoc processes and tools to extract digital evidence can jeopardise the integrity and credibility of evidence⁶. Therefore, we adopt an investigation framework in this research (similar to the approach undertaken by Martini and Choo^{45,46}, Martini *et al.*^{13,47} and Quick and Choo³⁹⁻⁴¹).

McKemmish⁴³ described forensic investigation in four stages: identification, preservation, analysis and presentation of digital evidence, which is similar to the four-stage NIST guidelines for mobile device forensics⁴⁸ and the four-stage cloud forensic framework⁴⁴. In this paper, we adapt these frameworks to guide our mobile device investigation. The integrated investigation framework comprises the following.

- (1) *Identification and collection.* Evidence was collected from the internal storage and internal memory of the mobile device and the network traffic was monitored. In our context, a Samsung Galaxy Tab II running Android version 4.2 and the internal storage of an Apple iPhone 5s running iOS version 7.1.2A bit-for-bit image of the internal memory and the internal storage of the Android device was acquired. On the iOS device, a backup of the internal storage using Apple's iTunes version 11.3.1 was acquired. Generated network traffic of user SN activities with both smartphones was captured using Wireshark version 1.4.4.
- (2) *Preservation.* MD5 and SHA1 hash values of each acquired file were calculated and, subsequently, verified so that we can detect any modification. In our investigation, the comparisons of hash values and timestamp metadata of files uploaded and then downloaded through Facebook, Twitter, LinkedIn and Google+ applications on both Android and iOS platforms revealed that the process of downloading files modifies file content and timestamps, as shown in Table 1. As expected, created, modified and last accessed timestamps of the downloaded file are matched to the timestamps of the destination folder on the smartphone following iOS and Android file system rules. Furthermore, since SN platforms are utilising resizing and compression algorithms during uploading files, the hash value of downloaded files differs from that of the original files.

Table 1. Summary of metadata preservation on Android and iOS platforms.

| | Android | | | | iOS | | | |
|------------------------|----------------------------|----------------------------------|------------------------------|----------------------------------|-------------------------------|----------------------------------|-----------------------------|----------------------------------|
| | Original file hash value | Original file timestamps | Downloaded File Hash Value | Timestamps | Original file hash value | Original file timestamps | Downloaded file hash value | Downloaded file timestamps |
| Facebook | MDS: 9547970B18E8EA | Created: 29/01/2014 12:31:49 AM | MDS: 0AB43E6B606 | Created: 11/11/2014 3:59:18 PM | MDS: FB40E2AA63F65F27 | Created: 8/02/2014 10:51:32 AM | MDS: 5F4EA700B1DA | Created: 12/11/2014 3:34:51 PM |
| | 972003AD4228A2D81 | Modified: 29/01/2014 12:31:50AM | AB074E703B39EF70E3F51 | Modified: 11/11/2014 3:59:18 PM | E135C70B70AFC29 | Modified: 8/02/2014 10:51:33 AM | 7301B3D5EED96083DEC0 | Modified: 12/11/2014 3:34:51 PM |
| | SHA1: 9813DEATEF8316487 | Accessed: 29/01/2014 12:31:46 AM | SHA1: D45AB3E30E6D7D67 | Accessed: 11/11/2014 3:59:18 PM | SHA1: EE6E0FFD128B854EB4ACBFA | Accessed: 8/02/2014 10:51:29 AM | SHA1: 055FCB9FCB7610868ABC | Accessed: 12/11/2014 3:34:51 PM |
| Twitter | 2C3767A20B77B724F5CE1095 | Created: 3/02/2014 5:48:13 PM | AE3E28AAD08674CD50DCCEF | Created: 11/11/2014 6:12:43 PM | 8C719D6D1A3433F | Created: 10/02/2014 2:34:48 PM | 7FB73DD39C0C6ED7AE5 | Created: 12/11/2014 4:28:14 PM |
| | MDS: 11BEC50CA473 | Accessed: 3/02/2014 5:48:13 PM | MDS: 508A414DC71493 | Accessed: 11/11/2014 6:12:43 PM | MDS: 8CB21B388DBAC98 | Accessed: 10/02/2014 2:34:48 PM | MDS: 804D3B7E7A11B2 | Accessed: 12/11/2014 4:28:14 PM |
| | DB6CS8B947B57EE71A | Modified: 3/02/2014 5:48:14 PM | F60FC581D736236AD | Modified: 11/11/2014 6:12:43 PM | DAB839FD7E492F6A | Modified: 10/02/2014 2:34:49 PM | E0D0E0F80D3897EEF53 | Modified: 12/11/2014 4:28:14 PM |
| LinkedIn | SHA1: 067D663D908EDC0597 | Accessed: 3/02/2014 5:48:10 PM | SHA1: E81E59E24C05C772894C40 | Accessed: 11/11/2014 6:12:43 PM | SHA1: 24A301559AAFCBC823CFB | Accessed: 10/02/2014 2:34:45 PM | SHA1: 0A9E1F93E351C79A0849A | Accessed: 12/11/2014 4:28:14 PM |
| | ACA87AB3E7B1CFD8A5F46D | Created: 5/02/2014 2:24:18 PM | EBB3D5F5C75140B11 | Created: 11/11/2014 10:34:26 PM | 64D5F7652B3B8312C8 | Created: 12/02/2014 8:43:33 PM | 444ADD347C33C189536 | Created: 12/11/2014 6:16:42 PM |
| | MDS: BB1E236CF9358 | Accessed: 5/02/2014 2:24:15 PM | MDS: 2565564169CA4 | Accessed: 11/11/2014 10:34:26 PM | MDS: FA4F7770EB298 | Accessed: 12/02/2014 8:43:30 PM | MDS: BA52ADBF5FDE | Accessed: 12/11/2014 6:16:42 PM |
| Google+ | 15E5BB714760B23F549 | Modified: 5/02/2014 2:24:19 PM | 579FEBC7844A09F7 | Modified: 11/11/2014 10:34:26 PM | 7DFECE93E4CF2DA88 | Modified: 12/02/2014 8:43:34 PM | 84188B83E0B476E8B287 | Modified: 12/11/2014 6:16:42 PM |
| | SHA1: 395E50118B029273 | Accessed: 5/02/2014 2:24:15 PM | SHA1: AAAB5E45CDBA4678B | Accessed: 11/11/2014 10:34:26 PM | SHA1: 9F5D00F5869F825269 | Accessed: 12/02/2014 8:43:30 PM | SHA1: 55A4B2418EA9850E | Accessed: 12/11/2014 6:16:42 PM |
| | 04970959C2241059EABE7F8D | Created: 7/02/2014 10:51:41 AM | 23FF46A76C14A58BC3DA4A0 | Created: 12/11/2014 1:18:23 PM | ACAD04B18189DC34A2DAE2 | Created: 14/02/2014 11:22:46 AM | 73FE23F20A18B01AC28E9A4B | Created: 12/11/2014 10:38:29 PM |
| Google+ | MDS: 47BAE32EB601F29 | Modified: 7/02/2014 10:51:42 AM | DB1E992B06F75F344E | Modified: 12/11/2014 1:18:23 PM | MDS: D9CAA3FF494949228 | Modified: 14/02/2014 11:22:47 AM | MDS: 59DASCBF3F501 | Modified: 12/11/2014 10:38:29 PM |
| | 642F07DC69EC368 | Accessed: 7/02/2014 10:51:38 AM | SHA1: A5B1B059A4863D998 | Accessed: 12/11/2014 1:18:23 PM | EAE3E35D4CA8068 | Accessed: 14/02/2014 11:22:43 AM | 63C1491D2CA39B5F59D | Accessed: 12/11/2014 10:38:29 PM |
| | SHA1: 30FDD0462ECA C5D34B3 | Accessed: 7/02/2014 10:51:38 AM | SHA1: A5B1B059A4863D998 | Accessed: 12/11/2014 1:18:23 PM | SHA1: 4577622CB04348C | Accessed: 14/02/2014 11:22:43 AM | SHA1: E17FAE72EF79756 | Accessed: 12/11/2014 10:38:29 PM |
| F3D4B2137331E92C38D97B | | BF60CA434D08A8F1FE59DB77 | | 3D14571EB65456D13445BCBF9 | | CBC58C37C9B1645757F7E8D1F | | |

- (3) *Examination and analysis.* Collected data from internal memory and internal storage of the devices was examined to determine possible data remnants of using the Facebook, Twitter, LinkedIn and Google+ applications on Android (refer to Section 3) and iOS (refer to Section 4), and to answer the first and the second question of this research respectively. Lastly, analysis of network capture files (refer to Section 5) will answer the third research question.
- (4) *Presentation.* A summary of findings and their forensic values are presented at this stage, as explained in Section 6 of this paper.

1.4. Outline

This paper is organised as follows: Section 2 describes the process of experiment setup and lists the tools and equipment used during this research. Sections 3 and 4 outline the analysis of the mentioned SN applications on Android and iOS devices respectively. Section 5 contains the examination of network traffic on both Android and iOS platforms. Finally, we conclude the paper with a summary of the results.

2. Experimental setup

A Samsung Galaxy Tab II running on Android 4.2 and an iPhone 5s running on iOS 7.1.2 were examined in this research. Both devices were wiped and restored to the default factory settings. The Facebook, Twitter, LinkedIn and Google+ applications were downloaded and installed through Play Store version 5.2.13 for Android and the built-in App Store on iOS. Two accounts were created ('bt.enron@gmail.com' on Android and 'bs.enron@gmail.com' on iOS) to conduct a total of five experiments on each platform to analyse Facebook, Twitter, LinkedIn and Google+. Each experiment includes five activities to mimic user attempts to login to the app, modify personal information, upload posts, exchange messages and upload comments. While these actions were being undertaken, Wireshark was running to capture the network traffic. The EDRM Enron Email data-set⁴⁹ was used to facilitate the research activities.

On the Samsung Galaxy Tab II, upon completion of each activity, a bit-for-bit image of the internal memory and internal storage was acquired using the *dd* command in Kali Linux version 1.1.0. Similarly, on iPhone 5s, a logical backup of internal storage was acquired upon completion of each activity, using Apple's iTunes version 11.3.1. Afterwards, MD5 and SHA1 hash values of the collected data were calculated using the *md5sum* and *sha1sum* commands built in to Kali Linux. The list of devices, applications and tools that are used in this research are provided in Table 2. AccessData FTK version 3.1.2 and HxD Hex Editor version 1.7.7.0 were used to analyse bit-for-bit images and iBackupBot version 5.1.9, Plist Editor for Windows version 1.0.1 and SQLite Database Browser version 1.3 were utilised to analyse the iOS backup files. Moreover, DCode software version 4.02 was used to decode the iOS backup files' timestamps.

A total of 20 physical images of Android internal memory, 20 physical images of Android internal storage, and 20 network captures of Android activities were created. Similarly, a total of 20 backups of iOS internal storage, and 20 network captures of iOS activities were created. The activities are named as *Type of Device* (*A* for Android and *i* for iOS), followed by *Type of SN platform* (*F* for Facebook, *T* for Twitter, *L* for

Table 2. Devices, applications and tools used.

| Devices, applications and tools | Specification |
|---------------------------------|---|
| iPhone 5s | iOS version 7.1.2 |
| Samsung Galaxy Tab II | Android version 4.2 |
| Facebook Application | version 4.3 for iOS, version 18.0.0 for Android |
| Twitter Application | version 3.2.2 for iOS, version 5.30.1 for Android |
| LinkedIn Application | version 1.1 for iOS, version 3.4.2 for Android |
| Google+ Application | version 3.1.1 for iOS, version 4.6.0 for Android |
| AccessData FTK | version 3.1.2 |
| HxD Hex Editor | version 1.7.7.0 |
| iBackupBot | version 5.1.9 |
| Plist Editor for Windows | version 1.0.1 |
| SQLite Database Browser | version 1.3 |
| iTunes | version 11.3.1 |
| Wireshark | version 1.10.1 |
| DCode | version 4.02 |

LinkedIn and G for Google+) followed by a sequential number. For example, AF1 represents the first Facebook experiment on the Android platform. Tables 3 and 4 show details of experiments conducted on the Android and iOS platforms.

3. Findings of the Android investigations

This section explains the analysis of the internal memory and internal storage of a Samsung Galaxy Tab II to determine data remnants after performing login, modifying personal information, uploading posts, exchanging messages and uploading comments activities in each of the Facebook, Twitter, LinkedIn and Google+ applications. In order to perform the analysis of internal memory and internal storage, each of the images were opened in AccessData FTK and HxD Hex Editor. The hex editor functionality allowed us to view the acquired images. The analysis was performed manually on each file to identify the file types, determine the headers and signatures of the files, search for related SN data, and determine the location of stored artefacts. Several keywords, such as usernames, *uid*, name and email address, were used to facilitate the searching of each file in order to detect SN artefacts. Further explanation on the process of analysis and the findings of the examination are provided in the following subsections.

3.1. Login information

Logging in to the Facebook app would leave the username (in this case bt.enron@gmail.com) in internal memory which can be detected by searching for 'www.facebook.com' as shown in Figure 1. Utilising this username and further searching the internal memory led to the identification of assigned Facebook *UID* and the timestamp of the last login to the application.

Similar to Facebook, searching the internal memory with 'www.twitter.com', 'www.linkedin.com' and 'www.plus.google.com' keywords revealed the username, *UID*, and last successful login time of the respective application. However, no trace of the user password could be detected in the internal memory, for any of these platforms.

Table 3. User details and sample data for Android experiments.

| SN applications on the Android device | Performed activities on the SN applications |
|---------------------------------------|--|
| Facebook (AF1-AF5) | AF1. Login username: bt.enron@gmail.com , password: hockey1* AF2. Modify personal info (Name: Barry Tycholiz, Friend: Hrap Gerry) AF3. Upload post (Content of Email 'End of Year Party') AF4. Exchange messages (Content of Email 'Hockey on Thurs') AF5. Upload comment (Content of Email 'Dinner Invitation') |
| Twitter (AT1-AT5) | AT1. Login username: bt.enron@gmail.com , password: hockey1* AT2. Modify personal info (Name: Barry Tycholiz, Friend: Hrap Gerry) AT3. Upload post (Content of Email 'Hockey on Thurs') AT4. Exchange messages (Content of Email 'Kern River 637') AT5. Upload comment (Content of Email 'Trip to Russia') |
| LinkedIn (AL1-AL5) | AL1. Login username: bt.enron@gmail.com , password: hockey1* AL2. Modify personal info (Name: Barry Tycholiz, Friend: Hrap Gerry) AL3. Upload post (Content of Email 'Hockey and Lunch') AL4. Exchange messages (Content of Email 'Kern River 637') AL5. Upload comment (Content of Email 'Hockey and Lunch') |
| Google+ (AG1-AG5) | AG1. Login username: bt.enron@gmail.com , password: hockey1* AG2. Modify personal info (Name: Barry Tycholiz, Friend: Hrap Gerry) AG3. Upload post (Content of Email 'Trip to Russia') AG4. Exchange messages (Content of Email 'Hockey on Thurs') AG5. Upload comment (Content of Email 'Trip to Russia') |

3.2. User profile information

When analysing the Facebook app, investigation of the internal storage was undertaken using the previously identified username as a keyword. We were able to identify date of birth, location, work and education background, email addresses, phone numbers and interests of the last logged in user, as shown in Figure 2. Moreover, the user's friends list, which includes the names and email addresses of the user's friends accompanied by URLs of their profile pages, are detectable as shown in Figure 3.

Investigation of users' profile information in the Twitter, LinkedIn and Google+ apps with the usernames identified in the previous section for each application, also resulted in discovery of the user's name, date of birth, biography, location, email

Table 4. User details and sample data for iOS experiments.

| SN applications on the iOS device | Performed activities on the SN applications |
|-----------------------------------|---|
| Facebook (iF1-iF5) | IF1. Login username: bs.enron@gmail.com , password: hockey1* IF2. Modify personal info (Name: Brian Stone, Friend: Jerry Strange) IF3. Upload post (Content of Email 'Great trip') IF4. Exchange messages (Content of Email 'Hockey on Thurs') IF5. Upload comment (Content of Email 'Dinner Invitation') |
| Twitter (iT1-iT5) | IT1. Login username: bs.enron@gmail.com , password: hockey1* IT2. Modify personal info (Name: Brian Stone, Friend: Jerry Strange) IT3. Upload post (Content of Email 'Trip to Russia') IT4. Exchange messages (Content of Email 'Kern River 637') IT5. Upload comment (Content of Email 'Trip to Russia') |
| LinkedIn (iL1-iL5) | IL1. Login username: bs.enron@gmail.com , password: hockey1* IL2. Modify personal info (Name: Brian Stone, Friend: Jerry Strange) IL3. Upload post (Content of Email 'Hockey and Lunch') IL4. Exchange messages (Content of Email 'Kern River 637') IL5. Upload comment (Content of Email 'Hockey and Lunch') |
| Google+ (iG1-iG5) | IG1. Login username: bs.enron@gmail.com , password: hockey1* IG2. Modify personal info (Name: Brian Stone, Friend: Jerry Strange) IG3. Upload post (Content of Email 'Trip to Russia') IG4. Exchange messages (Content of Email 'Hockey on Thurs') IG5. Upload comment (Content of Email 'Trip to Russia') |

address, work background, connections, friends list and URLs to each friend's profile picture for respective applications in the internal storage.

3.3. Uploading posts

The investigation revealed that posts uploaded using the Facebook application, and their corresponding timestamps, are detectable in the internal storage in plain text and can be recovered by searching for the user's *UID*, username or registered name (in this case bt.enron@gmail.com and Barry Tycholiz), as shown in Figure 4.

UID, username and registered name were also used in investigations of Twitter, LinkedIn and Google+ to detect uploaded posts, sent Tweets and corresponding timestamps within the internal storage.

| | | |
|----------|---|-------------------|
| 0124a490 | 41 31 42 30 32 4c 65 65-77 66 4d 63 55 4a 62 75 | A1B02LeewfMcUJbu |
| 0124a4a0 | 64 5a 43 65 4f 74 73 47-37 30 64 62 6b 61 46 4e | dZCeCtsG70dbkaFN |
| 0124a4b0 | 48 66 65 68 4e 76 73 58-35 6f 61 59 5a 43 76 66 | HfehNvsX5oaY2Cvf |
| 0124a4c0 | 52 5a 43 5a 43 35 4a 6b-58 35 70 45 30 79 4e 5a | RZCZC5JkX5pEoyNZ |
| 0124a4d0 | 41 71 78 45 62 31 87 5c-04 43 09 31 2f 61 75 74 | AqxEb1.. \C-1/aut |
| 0124a4e0 | 68 2f 75 73 65 72 5f 64-61 74 61 2f 66 62 5f 75 | h/user_data/fb_u |
| 0124a4f0 | 73 65 72 6e 61 6d 65 62-74 2e 65 6e 72 6f 6e 40 | sernamebt.enrcn@ |
| 0124a500 | 67 6d 61 69 6c 2e 63 6f-6d 50 87 5d 04 49 09 69 | gmail.ccnF-] I-1 |
| 0124a510 | 2f 61 75 74 68 2f 75 73-65 72 5f 64 61 74 61 2f | /auth/user_data/ |
| 0124a520 | 66 62 5f 73 65 73 73 69-6f 6e 5f 6b 65 79 35 2e | fb_session_key5. |
| 0124a530 | 6b 6d 34 6f 38 51 5a 75-4d 79 6d 4f 4c 41 2e 31 | kr4c8QZuMynCLA.1 |
| 0124a540 | 33 39 30 39 31 36 31 34-30 2e 36 31 2d 31 30 30 | 390916140.61-100 |
| 0124a550 | 30 30 37 36 36 35 36 39-37 33 32 37 20 87 5a 04 | 007665697327 .. |
| 0124a560 | 41 01 0f 2f 61 75 74 68-2f 75 73 65 72 5f 64 61 | A.. /auth/user_da |
| 0124a570 | 74 61 2f 66 62 5f 65 78-70 69 72 65 73 04 30 45 | ta/fb_expires_0E |
| 0124a580 | 87 5f 04 4f 09 4d 2f 61-75 74 68 2f 75 73 65 72 | ..C M/auth/user |
| 0124a590 | 5f 64 61 74 61 2f 66 62-5f 73 65 73 73 69 6f 6e | _data/fb_session |
| 0124a5a0 | 5f 73 65 63 72 65 74 61-32 35 63 64 39 66 34 32 | _secreta25cd9f42 |
| 0124a5b0 | 66 35 33 32 61 36 33 63-66 64 61 34 65 36 62 30 | f532a63cfd44e6b0 |
| 0124a5c0 | 39 37 64 35 64 34 35 87-1d 87 60 05 5f 09 8d 6b | 97d5d45.....k |
| 0124a5d0 | 2f 61 75 74 68 2f 75 73-65 72 5f 64 61 74 61 2f | /auth/user_data/ |

Figure 1. Facebook login artefact in Android.

| | | |
|----------|---|-------------------|
| 0020e6d0 | 72 63 2e 70 68 70 2f 76-32 2f 79 48 2f 72 2f 55 | rc.php/v2/yH/r/U |
| 0020e6e0 | 37 45 48 2d 31 55 30 5a-63 56 2e 70 6e 67 fb 83 | 7EH-1U0ZcV.png.. |
| 0020e6f0 | 74 65 78 74 fa 85 72 61-6e 67 65 73 f8 f9 45 54 | text..ranges..ET |
| 0020e700 | 42 6f 72 6e 20 6f 6e 20-4a 75 6e 65 20 32 30 2c | Born cn June 20, |
| 0020e710 | 20 31 39 38 30 fb 8b 63-6f 6e 63 69 73 65 5f 74 | 1980..ccncise_t |
| 0020e720 | 65 78 74 fa 46 f8 f9 45-54 42 6f 72 6e 20 6f 6e | ext-F..ETBorn cn |
| 0020e730 | 20 4a 75 6e 65 20 32 30-2c 20 31 39 38 30 fb fb | June 20, 1980.. |
| 0020e740 | f9 85 67 65 6e 64 65 72-43 4d 41 4c 45 81 69 64 | ..genderCM&E-id |
| 0020e750 | 4e 31 30 30 30 30 37 36-36 35 36 39 37 33 32 37 | N100007665697327 |
| 0020e760 | 83 6e 61 6d 65 4d 42 61-72 72 79 20 54 79 63 68 | nameBarry Tych |
| 0020e770 | 6f 6c 69 7a 89 61 6c 6c-5f 70 68 6f 6e 65 73 f8 | cliz_all_phones- |
| 0020e780 | f9 8d 61 6c 74 65 72 6e-61 74 65 5f 6e 61 6d 65 | ..alternate_nare |
| 0020e790 | 20 90 76 69 65 77 65 72-5f 6a 6f 69 6e 5f 73 74 | ..viewer_join_st |
| 0020e7a0 | 61 74 65 46 55 4e 4b 4e-4f 57 4e 96 66 65 61 74 | ateFUN&N&CWN-feat |
| 0020e7b0 | 75 72 65 64 5f 61 62 6f-75 74 5f 70 72 6f 66 69 | ured_about_profi |
| 0020e7c0 | 6c 65 73 fa 84 6e 6f 64-65 73 f8 f9 fb 8f 66 65 | les..nodes...fe |
| 0020e7d0 | 61 74 75 72 65 64 5f 66-72 69 65 6e 64 73 fa 4f | atured_friends_0 |
| 0020e7e0 | f8 fa 48 5f 55 4e 53 45-54 5f 4f 52 5f 55 4e 52 | ..H_UNSET_CR_UNR |
| 0020e7f0 | 45 43 4f 47 4e 49 5a 45-44 5f 45 4e 55 4d 5f 56 | ACOGNIZED_ENUM_V |
| 0020e800 | 41 4c 55 45 83 72 61 6e-6b 29 00 00 00 00 00 00 | ALUE..rank)..... |
| 0020e810 | 00 00 00 00 8d 66 61 63-65 70 69 6c 65 5f 6c 61 |facepile_la |

Figure 2. Facebook user's personal information artefact in Android.

3.4. Messaging

As shown in Figure 5, examination of the Facebook application revealed instant messages sent and received by the user, *UID* and name of the party who has received the message, along with timestamp metadata. These artefacts remain in the internal storage in plain text, and can be retrieved from the internal storage using *UID*, name, or username as search keywords.

When analysing Twitter, LinkedIn and Google+ apps, searching the internal storage with the user's *UID*, name, or username would result in locating the instant messages sent and received by the user, *UID* and name of the party who has received the message, along with timestamp metadata.

| | | |
|----------|---|------------------|
| 00cf0070 | 72 79 22 7d 2c 22 61 63-74 6f 72 73 22 3a 5b 7b | ry"},"actors":[{ |
| 00cf0080 | 22 69 64 22 3a 22 31 30-30 30 30 37 37 30 34 30 | "id":"1000077040 |
| 00cf0090 | 36 30 39 38 34 22 2c 22-6e 61 6d 65 22 3a 22 48 | 60984","name":"H |
| 00cf00a0 | 72 61 70 20 47 65 72 72-79 22 2c 22 72 61 6e 6b | rap Gerry","rank |
| 00cf00b0 | 22 3a 30 2e 30 2c 22 75-72 6c 22 3a 22 68 74 74 | |
| 00cf00c0 | 70 73 3a 2f 2f 6d 2e 66-61 63 65 62 6f 6f 6b 2e | ps://m.facebook. |
| 00cf00d0 | 63 6f 6d 2f 68 72 61 70-2e 67 65 72 72 79 22 2c | com/hrap.gerry", |
| 00cf00e0 | 22 66 72 69 65 6e 64 73-68 69 70 5f 73 74 61 74 | "friendship_stat |
| 00cf00f0 | 75 73 22 3a 22 55 4e 53-45 54 5f 4f 52 5f 55 4e | us":"UNSET_OR_UN |
| 00cf0100 | 52 45 43 4f 47 4e 49 5a-45 44 5f 45 4e 55 4d 5f | RECOGNIZED_ENUM_ |
| 00cf0110 | 56 41 4c 55 45 22 2c 22-5f 5f 74 79 70 65 5f 5f | VALUE","__type__ |
| 00cf0120 | 22 3a 7b 22 6e 61 6d 65-22 3a 22 55 73 65 72 22 | |
| 00cf0130 | 7d 2c 22 70 72 6f 66 69-6c 65 5f 70 69 63 74 75 | },"profile_pictu |
| 00cf0140 | 72 65 22 3a 7b 22 73 63-61 6c 65 22 3a 30 2e 30 | re":{"scale":0.0 |
| 00cf0150 | 2c 22 68 65 69 67 68 74-22 3a 36 30 2c 22 77 69 | ,"height":60,"wi |
| 00cf0160 | 64 74 68 22 3a 36 30 2c-22 75 72 69 22 3a 22 68 | dth":60,"uri":"h |
| 00cf0170 | 74 74 70 73 3a 2f 2f 66-62 63 64 6e 2d 70 72 6f | ttps://fbcdn-pro |
| 00cf0180 | 66 69 6c 65 2d 61 2e 61-6b 61 6d 61 69 68 64 2e | file-a.akamaihd. |
| 00cf0190 | 6e 65 74 2f 68 70 72 6f-66 69 6c 65 2d 61 6b 2d | net/hprofile-ak- |
| 00cf01a0 | 70 72 6e 31 2f 74 31 2f-73 36 30 78 36 30 2f 36 | prn1/t1/s60x60/6 |
| 00cf01b0 | 38 34 38 32 5f 31 33 37-34 37 31 35 31 30 36 31 | 8482_13747151061 |

Figure 3. Facebook friend list artefact in Android. (The user’s friend was identified as ‘Hrap Gerry’ with email address ‘hg.enron@gmail.com’.)

| | | |
|----------|---|------------------|
| 006fe930 | 7a 4d 79 4e 7a 6f 78 4d-7a 63 35 4d 7a 51 34 4f | zMyNzoxMzc5MzQ4O |
| 006fe940 | 44 41 79 4d 7a 4d 77 4e-6a 4d 77 22 2c 22 73 75 | EAyMzMwNjMw","su |
| 006fe950 | 62 73 74 6f 72 69 65 73-22 3a 5b 5d 2c 22 6d 65 | bstories":[],"me |
| 006fe960 | 73 73 61 67 65 22 3a 7b-22 72 61 6e 67 65 73 22 | ssage":{"ranges" |
| 006fe970 | 3a 5b 5d 2c 22 74 65 78-74 22 3a 22 49 20 61 6d | :[],"text":"I am |
| 006fe980 | 20 69 6e 2e 2e 2e 2e 2e-20 79 6f 75 20 6e 65 76 | in.... you nev |
| 006fe990 | 65 72 20 6e 65 65 64 20-74 6f 20 61 73 6b 20 21 | er need to ask ! |
| 006fe9a0 | 21 21 22 7d 2c 22 73 68-61 72 65 61 62 6c 65 22 | !!"},"shareable" |
| 006fe9b0 | 3a 7b 22 69 64 22 3a 22-63 33 52 76 63 6e 6b 36 | :{"id":"c3Rvcnk6 |
| 006fe9c0 | 55 7a 70 66 53 54 45 77-4d 44 41 77 4e 7a 59 32 | UzpfSTEwMCAwNzY2 |
| 006fe9d0 | 4e 54 59 35 4e 7a 4d 79-4e 7a 6f 78 4d 7a 63 35 | NTY5NzMyNzoxMzc5 |
| 006fe9e0 | 4d 7a 51 34 4f 44 41 79-4d 7a 4d 77 4e 6a 4d 77 | MzQ4ODAyMzMwNjMw |

Figure 4. Facebook uploading posts Artefact in Android.

3.5. Uploading comments

The Facebook app stores comments uploaded or received by the user on the internal storage in plain text, along with the upload time, as shown in Figure 6. These artefacts contain the information of the person who has uploaded the comment, the relevant post that the comment was posted on, and the content of the comment itself, and can be recovered from the internal storage with a search for the *UID*, username, or email address of the user.

Similarly, searching the internal storage with the user’s *UID*, username, and email address revealed the uploaded comments and timestamp metadata for Twitter, LinkedIn and Google+.

| | | |
|----------|---|--------------------|
| 0131aba0 | 37 39 33 34 34 30 32 3a-34 31 34 31 37 34 37 38 | 7934402:41417478 |
| 0131abb0 | 36 38 31 38 62 38 32 66-36 37 74 5f 6d 69 64 2e | 6818b82f67c_mid. |
| 0131abc0 | 31 33 39 30 39 32 37 39-33 34 34 30 32 3a 34 31 | 1390927934402:41 |
| 0131abd0 | 34 31 37 34 37 38 36 38-31 38 62 38 32 66 36 37 | 4174786818b82f67 |
| 0131abe0 | 13 4d 91 96 42 e8 66 40-49 20 61 6d 20 67 6f 69 | .M..B.f@I ar gol |
| 0131abf0 | 6e 67 20 74 6f 20 73 6b-61 74 65 20 61 72 6f 75 | ng to skate arou |
| 0131ac00 | 6e 64 20 6c 69 6b 65 20-50 65 72 72 79 20 54 75 | nd like Ferry Tu |
| 0131ac10 | 72 6e 62 75 6c 6c 2e 2e-2e 2e 2e 20 49 20 73 68 | rnbull..... I sh |
| 0131ac20 | 6f 75 6c 64 20 62 65 20-67 6f 6f 64 20 66 6f 72 | ould be good for |
| 0131ac30 | 20 61 20 68 61 74 20 74-72 69 63 6b 2e 2e 2e 2e | a hot trick.... |
| 0131ac40 | 20 49 20 77 69 6c 6c 20-70 75 74 20 79 6f 75 72 | I will put your |
| 0131ac50 | 20 70 75 74 74 65 72 20-69 6e 20 74 68 65 20 74 | putter in the t |
| 0131ac60 | 72 75 6e 6b 2e 2e 2e 2e-42 54 7b 22 65 6d 61 69 | runk....BI{"erai |
| 0131ac70 | 6c 22 3a 22 31 30 30 30-30 37 36 36 35 36 39 37 | l":"100007665697 |
| 0131ac80 | 33 32 37 40 66 61 63 65-62 6f 6f 6b 2e 63 6f 6d | 327@facebckk.com |
| 0131ac90 | 22 2c 22 75 73 65 72 5f-6b 65 79 22 3a 22 46 41 | ","user_key":"FA |
| 0131aca0 | 43 45 42 4f 4f 4b 3a 31-30 30 30 30 37 36 36 35 | CEBCK:100007665 |
| 0131acb0 | 36 39 37 33 32 37 22 2c-22 6e 61 6d 65 22 3a 2d | 697327","name": |
| 0131acc0 | 42 61 72 72 79 20 54 79-63 68 6f 6c 69 7a 22 7d | Barry Tycholiz"] |
| 0131acd0 | 01 43 d9 c3 f3 bc 5b 5d-5b 5d 5b 5d 7b 22 6c 61 | .C....[[]][[]]{"la |
| 0131ace0 | 74 69 74 75 64 65 22 3a-33 2e 30 33 38 33 36 34 | titude":3.038364 |

Figure 5. Facebook instant messaging Artefact in Android.

| | | |
|----------|---|--------------------|
| 00d06ef0 | 73 65 74 22 3a 30 7d 5d-2c 22 74 65 78 74 22 3a | set":0]], "text": |
| 00d06f00 | 22 48 72 61 70 20 47 65-72 72 79 20 63 6f 6d 6d | "Hrap Gerry corrm |
| 00d06f10 | 65 6e 74 65 64 20 6f 6e-20 79 6f 75 72 20 70 68 | ented on your ph |
| 00d06f20 | 6f 74 6f 3a 20 5c 22 77-61 74 73 20 74 68 65 20 | etc: \wats the |
| 00d06f30 | 6e 61 6d 65 20 6f 66 20-72 65 73 74 61 75 72 61 | name of restaura |
| 00d06f40 | 6e 74 3f 5c 22 22 2c 22-61 67 67 72 65 67 61 74 | nt?\\"", "aggregat |
| 00d06f50 | 65 64 5f 72 61 6e 67 65-73 22 3a 5b 5d 7d 2c 22 | ed_ranges":{]], " |
| 00d06f60 | 63 72 65 61 74 69 6f 6e-5f 74 69 6d 65 22 3a 21 | creation_time":1 |
| 00d06f70 | 33 39 30 39 32 38 36 30-33 2c 22 73 75 62 73 74 | 390928603,"subst |
| 00d06f80 | 6f 72 79 5f 63 6f 75 6e-74 22 3a 30 2c 22 68 61 | cry_ccunt":0,"ha |
| 00d06f90 | 73 5f 63 6f 6d 70 72 65-68 65 6e 73 69 76 65 5f | a_ccmprehensive |
| 00d06fa0 | 74 69 74 6c 65 22 3a 66-61 6c 73 65 2c 22 63 61 | title":false,"ca |
| 00d06fb0 | 6e 5f 76 69 65 77 65 72-5f 65 64 69 74 22 3a 66 | n_viewer_edit":f |
| 00d06fc0 | 61 6c 73 65 2c 22 63 61-6e 5f 76 69 65 77 65 72 | alse,"can_viewer |
| 00d06fd0 | 5f 64 65 6c 65 74 65 22-3a 66 61 6c 73 65 2c 22 | _delete":false," |
| 00d06fe0 | 63 61 6e 5f 76 69 65 77-65 72 5f 61 70 70 65 6e | can_viewer_appen |
| 00d06ff0 | 64 5f 70 68 6f 74 6f 73-22 3a 66 61 6c 73 65 7d | d_photos":false} |
| 00d07000 | 0d 00 00 00 01 02 63 00-02 63 00 1c 33 32 33 33 | -----c-c-3233 |
| 00d07010 | 30 31 37 37 5f 39 37 39-37 38 38 39 31 38 5f 6e | 0177_979788918 n |
| 00d07020 | 2e 6a 70 67 2e 77 65 62-70 22 7d 2c 22 69 6d 61 | .jpg.webp"},"ira |

Figure 6. Facebook uploading comments Artefact in Android.

4. Findings of the iOS investigations

This section explains the analysis of acquired iOS backup files to determine the data remnants after performing login, modifying personal information, uploading posts, exchanging messages and uploading comments in the Facebook, Twitter, LinkedIn and Google+ applications. In order to perform the analysis of iOS backup files, a tool called iBackupBot was utilised. The analysis was performed manually on each file to identify the file types, determine the headers and signatures of the files, search for related SN data and determine the location of stored artefacts. The backup files contained several files with the .plist and .sqlite formats. Plist editor was used to view the .plist files content and SQLite Database Browser was utilised to open the .sqlite files. Several

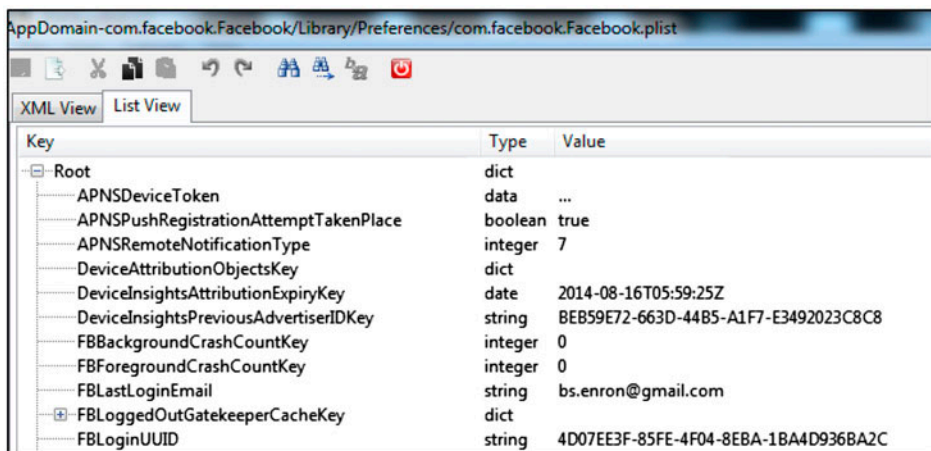
keywords, such as usernames, *uid*, name and email address, were then used to search each file in order to detect SN artefacts. Further explanation on the process of analysis and the findings of the examination are provided in the following subsections.

Login information

Searching in acquired backup files using ‘www.facebook.com’, ‘www.twitter.com’, ‘www.linkedin.com’ and ‘www.plus.google.com’ revealed the username, *UID* and timestamp of the last successful login for each platform as shown for Facebook in Figure 7. These artefacts were located in the ‘com.facebook.Facebook.plist’, ‘com.ate-bits.Tweetie2.plist’, ‘com.linkedin.Linkedin.plist’ and ‘loggedInUserKey.plist’ files for Facebook, Twitter, LinkedIn and Google+ respectively. However, no password remnant could be detected for any SN platform within the acquired backup files.

User profile Information

The acquired backup files were investigated using the *UID* and username for each SN platform. The Facebook app would leave the user’s friend list, phone number, email address, age, place of work, city of residence, interests and GPS location in the ‘kFBPrivacySettingCachedSettings-1401330084.plist’ file. The Twitter app would leave the user’s name, email address, place of work, biography, location, followers list, people followed by, URL pointing to user’s profile picture, along with the username and email address of the other Twitter accounts that the user is following or being followed by in the ‘app.acct.bsenron.typeahead_users.plist’ file. In the LinkedIn app, artefacts including the user’s name, email address, employer and position, along with a URL pointing to the user’s profile picture were detected in the ‘com.linkedin.Linkedin.plist’ file as shown in Figure 8. Users’ LinkedIn connections, listed skills, resume, email addresses, connections and URLs showing the profile picture of each connection were extracted from the ‘LINUSStreamV2CacheKey.plist’ file. The Google+ app left the user’s name, email address and a URL redirecting to the user’s profile picture in a file named ‘loggedInUserKey.plist’.



| Key | Type | Value |
|---------------------------------------|---------|--------------------------------------|
| -Root | dict | |
| APNSDeviceToken | data | ... |
| APNSPushRegistrationAttemptTakenPlace | boolean | true |
| APNSRemoteNotificationType | integer | 7 |
| DeviceAttributionObjectsKey | dict | |
| DeviceInsightsAttributionExpiryKey | date | 2014-08-16T05:59:25Z |
| DeviceInsightsPreviousAdvertiserIDKey | string | BE859E72-663D-4485-A1F7-E3492023C8C8 |
| FBBackgroundCrashCountKey | integer | 0 |
| FBForegroundCrashCountKey | integer | 0 |
| FBLastLoginEmail | string | bs.enron@gmail.com |
| FBLoggedOutGatekeeperCacheKey | dict | |
| FBLoginUUID | string | 4D07EE3F-85FE-4F04-8EBA-1BA4D936BA2C |

Figure 7. Facebook login artefact in iOS.

```

00002200 65 6D 61 69 6C 5A 68 61 73 50 69 63 74 75 72 65 emailZhasPicture
00002210 59 6E 61 6D 65 3A 31 4D 46 56 5F 10 10 4D 61 6E Yname:1MFV ..Man
00002220 61 67 65 72 20 61 74 20 45 6E 72 6F 6E 55 53 74 ager at EnronUSSt
00002230 6F 6E 65 59 33 32 35 34 34 36 37 32 36 10 00 55 oneY325446726..U
00002240 42 72 69 61 6E 5F 10 4A 68 74 74 70 3A 2F 2F 6D Brian .Jhttp://m
00002250 2E 63 2E 6C 6E 6B 64 2E 6C 69 63 64 6E 2E 63 6F .c.lnkd.licdn.co
00002260 6D 2F 6D 70 72 2F 6D 70 72 2F 73 68 72 69 6E 6E m/mpr/mpr/shrink
00002270 5F 38 30 5F 38 30 2F 70 2F 33 2F 30 30 30 2F 32 _80_80/p/3/000/2
00002280 31 62 2F 32 66 63 2F 30 65 38 32 63 36 32 2E 6A lb/2fc/0e82c62.j
00002290 70 67 5B 42 72 69 61 6E 20 53 74 6F 6E 65 5F 10 pg[Brian Stone .
000022A0 12 62 73 2E 65 6E 72 6F 6E 40 67 6D 61 69 6C 2E .bs.enron@gmail.
000022B0 63 6F 6D 09 09 09 08 08 09 AA 01 8E 01 97 01 9B com.....*.Z.-. >

```

Figure 8. LinkedIn user's personal information Artefact in iOS.

Uploading posts

Investigation of backup files using the user's name and email address revealed that the Facebook app leaves URLs showing public posts uploaded by the user in a file named 'com.facebook.Facebook.plist'. The contents and timestamp of sent tweets in the Twitter app are left in a file called 'com.atebits.Tweetie2.plist'. In the LinkedIn app, uploaded posts remain in a file named 'liv2profile325446726.plist', as shown in Figure 9. In the Google+ app, a SQLite file named 'MediaUploader_d9a336d6e29858e450949fcf0b-b662b2' was detected, containing URLs pointing to pictures posted by the user along with their timestamps and hash values.

Messaging

Investigation of backup files using the *UID*, name and email address of the user revealed that the Facebook app leaves message content in a file named 'Dynamic Dictionary.dat'. This file holds snippets of text that the user types using the device's keyboard. Moreover, the time of the last inbox update, which indicates the last message received, can be retrieved from the 'com.facebook.Facebook.plist' file. The Twitter and LinkedIn apps also reveal the content of messages sent by the user (in this case Brian

```

00002C40 73 74 72 69 6E 67 3E 43 68 65 63 6B 20 6F 75 74 string>Check out
00002C50 20 74 68 69 73 20 75 70 64 61 74 65 20 66 72 6F this update fro
00002C60 6D 20 42 72 69 61 6E 20 53 74 6F 6E 65 20 0A 0A m Brian Stone ..
00002C70 20 74 68 61 6E 6B 73 20 66 6F 72 20 74 68 65 20 thanks for the
00002C80 67 61 6D 65 20 79 65 73 74 65 72 64 61 79 2E 2E game yesterday..
00002C90 2E 20 61 6E 64 20 6C 75 6E 63 68 2E 20 69 20 75 . and lunch. i u
00002CA0 6E 64 65 72 73 74 61 6E 64 20 74 68 61 74 20 49 nderstand that I
00002CB0 20 63 72 65 61 74 65 64 20 61 6E 20 65 72 72 6F created an erro
00002CC0 72 20 69 6E 20 6D 79 20 63 61 6C 63 75 6C 61 74 r in my calculat
00002CD0 69 6F 6E 2E 20 73 6F 75 6E 64 73 20 6C 69 6B 65 ion. sounds like
00002CE0 20 39 35 20 77 61 73 20 74 68 65 20 72 69 67 68 95 was the righ
00002CF0 74 20 6E 75 6D 62 65 72 20 6E 6F 74 20 31 30 35 t number not 105
00002D00 20 66 6F 72 20 74 68 65 20 74 6F 74 61 6C 2E 3C for the total.*
00002D10 2F 73 74 72 69 6E 67 3E 0A 09 09 09 09 09 09 /string>.....

```

Figure 9. LinkedIn uploading posts Artefact in iOS.

Stone) in the ‘DynamicDictionary.dat’ file as shown in Figure 10. The Google+ app did not leave any artefacts with forensic value relevant to messages sent and received by the user that we could detect in the iOS backup files.

Uploading comments

Investigation of iOS backup files using the user’s *UID*, name and email address revealed that the Facebook app leaves URL artefacts showing comments uploaded on public posts in the ‘com.facebook.Facebook.plist’ file. The Twitter app leaves detectable content of uploaded comments in the ‘DynamicDictionary.dat’ file. As shown in Figure 11, the LinkedIn app would leave the full content of uploaded comments, upload time, comments received by the user and the name of the other users (in this case Jerry Strange) who commented on posts uploaded by the user (Brian Stone) in the ‘liv2profile325446726.plist’ file. Examination of iOS backup files in relation to comments uploaded by the user of the Google+ app did not result in detection of any artefacts with forensic value.

5. Network traffic analysis

When accessing the Facebook, Twitter, LinkedIn and Google+ applications, a session would be established over TCP port 443. Facebook’s SSL certificates for api.facebook.com and LinkedIn’s SSL certificates for api.linkedin.com are issued by DigiCert, while Twitter’s SSL certificates for api.twitter.com and Google+ SSL certificates for api.plus.google.com are issued by Verisign. A session with Google Analytic services is established during the sign-in process for all four applications.

All application layer data are encrypted with TLSv1.2 protocols. Therefore, only the user’s IP address, domain name of connected SN sites and corresponding session timestamps can be determined from network traffic. However, the corresponding timestamp can be used as an aid in timelining user activities. Figure 12 shows the network packet containing Facebook’s SSL certificate from DigiCert and Facebook’s application data encrypted using TLSv1.2.

```
00000040 74 65 63 74 75 72 65 00 03 00 61 72 6F 75 6E 64 tecture...around
00000050 00 01 00 61 73 6B 00 01 00 61 74 74 65 6E 64 00 ...ask...attend.
00000060 01 00 61 75 74 68 65 6E 74 69 63 61 74 69 6F 6E ..authentication
```

Figure 10. Twitter instant messaging Artefact in iOS.

```
000041C0 78 74 3C 2F 6B 65 79 3E 0A 09 09 09 09 09 09 xt</key>.....
000041D0 09 09 09 3C 73 74 72 69 6E 67 3E 64 6F 65 73 20 ...<string>does
000041E0 6E 6F 74 20 6D 61 74 74 65 72 2C 20 61 6E 64 20 not matter, and
000041F0 79 6F 75 72 20 77 65 6C 63 6F 6D 65 2E 20 6E 65 your welcome. ne
00004200 78 74 20 74 69 6D 65 20 6C 65 74 20 6D 65 20 63 xt time let me c
00004210 6F 75 6E 74 20 6C 6F 6C 3C 2F 73 74 72 69 6E 67 ount look</string
00004220 3E 0A 09 09 09 09 09 09 09 09 09 09 3C 2F 64 69 63 >.....</dic
```

Figure 11. LinkedIn uploading comments Artefact in iOS.

Downloaded by [Hacettepe University] at 01:06 11 August 2015

| No. | Time | Source | Destination | Protocol | Length | Info |
|--|---|----------------------------|---------------------------------------|----------|--------|---|
| // | 6.18285200 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 1441 | Application data |
| 78 | 6.18293600 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 101 | Application data |
| 111 | 8.00408000 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->61963 [ACK] Seq=6698 Ack=2188 win=2043 Len=0 |
| 112 | 8.00414000 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 99 | Application data |
| 114 | 8.00430800 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 85 | Encrypted Alert |
| 115 | 8.00491000 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->61963 [FFN, ACK] Seq=6774 Ack=2188 win=2043 Len=0 |
| 2450 | 32.12645900 | 31.13.67.1 | 192.168.1.84 | TCP | 66 | 443->62181 [SYN, ACK] Seq=0 Ack=1 win=15360 Len=0 MSS=1410 SACK_PERM=1 WS=256 |
| 2454 | 32.16236400 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->62181 [ACK] Seq=1 Ack=218 win=15360 Len=0 |
| 2455 | 32.16244100 | 31.13.67.1 | 192.168.1.84 | TCP | 501 | [TCP Previous segment not captured] [TCP segment of a reassembled PDU] |
| 2457 | 32.16261400 | 31.13.67.1 | 192.168.1.84 | TCP | 1464 | [TCP Out-of-order] [TCP segment of a reassembled PDU] |
| 2459 | 32.16274800 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 1464 | [TCP Fast Retransmission] Server: hello |
| 2465 | 32.21154100 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->62181 [ACK] Seq=3268 Ack=380 win=16384 Len=0 |
| 2466 | 32.21161800 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 312 | New session ticket, Change Cipher Spec, Encrypted Handshake Message |
| 2467 | 32.22167900 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 127 | Application data |
| 2469 | 32.22716500 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->62181 [ACK] Seq=3599 Ack=437 win=16384 Len=0 |
| 2470 | 32.22724000 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->62181 [ACK] Seq=3599 Ack=482 win=16384 Len=0 |
| 2471 | 32.22996400 | 31.13.67.1 | 192.168.1.84 | TCP | 54 | 443->62181 [ACK] Seq=3599 Ack=1349 win=19200 Len=0 |
| 2472 | 32.23002500 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 99 | Application data |
| 2475 | 32.46219700 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 431 | Application data |
| 2545 | 34.52437800 | 31.13.67.1 | 192.168.1.84 | TLSV1.2 | 99 | Application data |
| Frame 2457: | 1464 bytes on wire (11712 bits), 1464 bytes captured (11712 bits) on interface 0 | | | | | |
| Ethernet II, Src: | TechniCo_36:25:68 (9c:97:26:36:25:68), Dst: IntelCor_d2:a8:14 (58:94:6b:d2:a8:14) | | | | | |
| Internet Protocol Version 4, Src: | 31.13.67.1 (31.13.67.1), Dst: 192.168.1.84 (192.168.1.84) | | | | | |
| Transmission Control Protocol, Src Port: | 443 (4433), Dst Port: 62181 (62181), Seq: 1411, Ack: 218, Len: 1410 | | | | | |
| 00a0 | 0d 01 01 05 05 00 30 6c | 31 0b 30 09 06 03 55 04 |01 1.0...u. | | | |
| 00c0 | 44 63 87 69 43 65 72 74 | 20 49 6e 23 31 19 30 17 | ..USI..incl.i.o. | | | |
| 00e0 | 06 03 55 04 0b 13 10 77 | 77 77 2e 64 69 67 69 63 | ..u..w ww.digic | | | |
| 00f0 | 13 22 44 69 67 6f 6d 31 | 2b 30 29 06 03 55 04 03 | ert.coml +0)..u.. | | | |
| 00ff | 05 22 24 26 63 6f 6d 31 | 72 74 20 48 69 67 68 20 | ..Digitce rt High | | | |
| 0100 | 41 73 73 72 61 6e 63 | 65 20 45 26 20 52 6f 6f | Assuranc e EV Roo | | | |
| 0110 | 74 20 43 10 1e 17 0d | 30 38 30 34 30 32 31 32 | t CA0... 08040212 | | | |
| 0120 | 30 30 30 5a 16 37 0d | 32 30 34 30 33 30 30 30 | 0000Z..2 20403000 | | | |
| 0130 | 30 30 30 5a 30 66 31 | 0b 30 09 06 03 55 04 06 13 | 000Z0F1. 0...u.. | | | |
| 0140 | 02 55 33 31 15 30 13 06 | 03 55 04 13 0c 44 69 | ..USI..0..u...di | | | |
| 0150 | 67 69 43 13 12 77 77 77 | 6e 63 28 27 20 17 0e 73 | gicert I ncl.i.0...u.....www .digictr | | | |

Figure 12. Facebook network traffic artefact.

Table 5. Summary of findings from investigation of SN applications on Android and iOS platforms.

| | Facebook | | Twitter | | LinkedIn | | Google+ | |
|---------------------|----------|-----|---------|-----|----------|-----|---------|-----|
| | Android | iOS | Android | iOS | Android | iOS | Android | iOS |
| Login | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Username | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Password | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| Name | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Contact information | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Profile picture | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Work and education | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Location | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Friend list | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Posts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Messages | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Comments | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| IP address | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

6. Concluding remarks

Investigations of the Facebook Android app showed that the username, assigned *UID* and time of last successful login could be recovered from the device’s internal memory. The user’s name, email address, phone number, profile picture, work and education background, location, friend list, posts, messages, comments and timestamp metadata could be found in the device’s internal storage. The Facebook application would leave in iOS backup files the username, assigned *UID*, name, email addresses, phone numbers, profile picture, work and education background, location, friend list, posts, content of messages, comments and timestamp metadata for last successful login, uploaded posts, uploaded comments and the last time the user’s inbox was updated.

The Twitter app for Android leaves the assigned *UID* and time for last successful login on the device’s internal memory, and the user’s name, email address, phone number, profile picture, work and education background, location, friend list, posts, messages, comments and timestamp metadata on the device’s internal storage. The Twitter app for iOS leaves in the iOS backup files the username, assigned *UID*, name, email addresses, phone numbers, profile picture, work and education background, location, friend list, content of the tweets, content of the messages and comments, and timestamp metadata for successful login and recent tweets.

The remnants of the Android LinkedIn application found on the device’s internal memory are the username, assigned *UID* and time for the last successful login, and artefacts found in the Android internal storage are the user’s name, email addresses, phone numbers, profile picture, work and educational background, location, friend list, posts, messages, comments and timestamp metadata on Android internal storage. Remnants of the LinkedIn application to be found on iOS backup files include the username, assigned *UID*, name, email addresses, phone numbers, profile picture, work and education background, location, friend list, posts, comments, content of messages, and timestamp metadata for the last successful login, uploaded posts and uploaded comments.

The remaining artefacts of Android’s Google+ application are the username, assigned *UID* and the time for last successful login on the device’s internal memory; and the user’s name, email address, phone number, profile picture, work and education

background, location, friend list, posts, messages, comments and timestamp metadata on the internal storage. On iOS, the Google+ app leaves the username, assigned *UID*, name, profile picture, email addresses, phone numbers, pictures uploaded in posts and timestamp metadata for the last successful login.

A summary of findings from our investigations is presented in Table 5.

In this research we have adapted the cloud forensic framework of Martini and Choo⁴⁴, which integrates both McKemmish⁴³ and Ayers *et al.*⁴⁸ general digital forensic frameworks, to guide our investigations. Using our case study applications, we have demonstrated the utility of the framework for non-cloud investigations. We also believe that the framework of Martini and Choo⁴⁴ could be used to investigate other similar smartphone platforms. However, the reported findings are likely to differ between applications and platforms. For example, different smartphones use different operating systems (or different versions) and differences in operating system structure and file types may affect the type and amount of artefacts that could be recovered. Smartphone applications are also constantly being updated by their vendors, which will change the structure, functionality and features of newer applications. Therefore, this could affect the type and amount of artefacts that could be recovered. Tools would also have to keep pace with hardware and software changes, which could result in different artefacts recovered. Therefore, future research would include extending this research to other newer applications such as games, health, instant messengers, cloud storages and banking, and newer smartphone platforms, which would allow us to have an up-to-date forensic understanding.

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