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A USER-ORIENTED NETWORK FORENSIC ANALYSER: THE DESIGN OF A HIGH-LEVEL PROTOCOL ANALYSER

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Abstract

Network forensics is becoming an increasingly important tool in the investigation of cyber and computer-assisted crimes. Unfortunately, whilst much effort has been undertaken in developing computer forensic file system analysers (e.g. Encase and FTK), such focus has not been given to Network Forensic Analysis Tools (NFATs). The single biggest barrier to effective NFATs is the handling of large volumes of low-level traffic and being able to exact and interpret forensic artefacts and their context – for example, being able extract and render application-level objects (such as emails, web pages and documents) from the low-level TCP/IP traffic but also understand how these applications/artefacts are being used. Whilst some studies and tools are beginning to achieve object extraction, results to date are limited to basic objects. No research has focused upon analysing network traffic to understand the nature of its use – not simply looking at the fact a person requested a webpage, but how long they spend on the application and what interactions did they have with whilst using the service (e.g. posting an image, or engaging in an instant message chat). This additional layer of information can provide an investigator with a far more rich and complete understanding of a suspect's activities. To this end, this paper presents an investigation into the ability to derive high-level application usage characteristics from low-level network traffic meta-data. The paper presents a three application scenarios – web surfing, communications and social networking and demonstrates it is possible to derive the user interactions (e.g. page loading, chatting and file sharing) within these systems. The paper continues to present a framework that builds upon this capability to provide a robust, flexible and user-friendly NFAT that provides access to a greater range of forensic information in a far easier format.

Keywords

Digital Forensics, Network Forensic Analysis Tool, Network Forensics, Analysis, Correlation, Visualisation

INTRODUCTION

In recent years, the number, scale and variety of cyber enabled crimes increases on a yearly basis (McGuire and Dowling, 2013). Indeed, criminals can use their computers not only for traditional crimes (e.g. fraud and money laundry) but also for newly formed attacks (e.g. phishing). By utilising well-established computer forensic tools (e.g. FTK) and techniques, investigators can thoroughly examine suspect's computing devices for evidence of wrong doings (Acessdata, 2013; DFRWS, 2001; Garfinkel, 2010; ISO 27037, 2012). However, technically competent criminals can take the advantage of the existence of anti-forensic tools and techniques (such as overwriting data and metadata, exploiting the vulnerabilities in computer forensic tools and detecting the presence of computer forensic tools) to wipe their computers, leaving little trace for forensic investigators to find (Garfinkel, 2007; Pajek and Pimenidis, 2009).

With the aim of providing additional assistance against computer enabled crimes, network forensics tries to solve the problem by examining network traffics which user has less control over. Nonetheless, being able to trace user activities in an effective and timely manner can be extremely challenging due to several factors, such as the sheer volume of network traffic and the ability of existing forensic tools (Pilli *et al.*, 2010). Indeed, annual global IP traffic would surpass the zettabyte threshold in 2016 according to a Cisco's prediction (Cisco, 2014). Regarding the tools, limited level of analysis and artefact extraction can be performed by network forensic examiners in the past despite a selection of tools could have been utilised; more recent advances in Network Forensic Analysis Tools (NFATs) are beginning to incorporate common object identification and extraction. For example, the tools such as Xplico Open Source Network Forensic Analysis Tool (Xplico, 2007) and PyFlag (Cohen, 2008) can reconstruct a TCP session, extract the payload and perform a data carve against it to identify if any files are contained within it. Nonetheless, these tools can be utilised to view data only at TCP/IP levels of data abstraction

but not at the user activity levels. As a result, a tool that can process larger amount of traffic in a timely manner and also offer additional analysis upon user activities is required for the modern network forensics domain.

This paper proposes a novel network forensic analysis tool capable of generating high level information by analysing raw network traffic from an investigation perspective. This high-level information goes beyond simply identifying which servers have been contacted and data carving the payload but provides the investigator with an understanding of what the user was doing whilst accessing those services. For example, the approach will not merely identify what website is being visited but for what purpose and what user interactions take place.

The paper is structured as follows. Section 2 presents a literature review of the current tools and techniques used in network forensics. Section 3 discusses an experiment into the analysis of network-level traffic and the identification of application-level user interactions. A framework for the User-Oriented Network Forensic Analysis Tool (UO-NFAT) along with an illustration of the tool's dashboard in presented in Section 4. Section 5 contains the conclusions and the future directions of the research.

EXISTING WORK ON NETWORK FORENSICS

Network forensics is defined as the "capture, record and analysis of the network events in order to discover the source of security attacks or other problem incidents" (Pilli *et al.*, 2010). As every single time an attack takes place in a network, from that point onwards, the network traffic becomes an essential piece of the evidence. By utilising network forensic tools, investigators can identify potential evidence from existing network traffic logs when incidents are reported. However, network forensic investigations always have to deal with two major challenges: the quantity problem and the complexity problem (Merkle, 2008). The volume of data in any network these days is enormous (ITU-T, 2013). Also, filtering the traffic in an intelligent manner that seeks to reduce the complications of the entire analysis process is a challenging task (Mukkamala, 2003). Furthermore, an analysis of some of the most commonly used network forensic analysis tools was conducted based on the type of appliance, their functionalities, whether they are commercial or open source products. These tools are NetIntercept (NIKSUN, 2010), NetDetector (NIKSUN, 2013; Casey, 2004), NetWitness (RSA, 2012; Chowdhury and Vidalis, 2012), SilentRunner (AccessData, 2010), InfiniStream (Netscout, 2012), Solera DeepSee 5150 (Solera Networks, 2009), OmniPeek (WildPackets, 2012), NetResident (TamoSoft, 2009), PyFlag (Cohen, 2008), NetworkMiner (NETRESEC, 2013; Fahmy *et al.*, 2012), Xplico Open Source Network Forensic Analysis Tool (Xplico, 2007) and Iris Network Traffic Analyser (Lyonesse Software, 2008). It's been observed that many of the commercial network forensic analysis tools are very expensive and they do not serve the requirements that are needed to be fulfilled in order to carry out the investigation in a cost and time effective and an efficient manner. A good network forensic analysis tool should exhibit the capability to:

- Identify the protocols and reconstruct the protocol stream in a reliable manner;
- Reduce the large volume of data by using methods for extracting items of interest such as usernames, passwords, top talkers etc.;
- Recover digital objects such as e-mail messages, documents, images etc. from the network traffic before analysing for evidences;
- Logically search for keywords and perform regular expression searches;
- Create the audit log (to document all the examiner's activities);
- Operate in read-only mode during examination (tool should not be capable of accessing any content from web servers while reconstructing and displaying any webpage; the reconstruction must only be made from the captured network traffic);
- Perform case management (a feature exhibited by computer forensic tools);
- Understand what and how a service is being used for;
- Correlate evidence between services to aid in creating a meaningful chronology of events;
- Use advanced data analytics to predict the likelihood of future events.

Experimenting with some of the open source NFATs showed that there are limitations in the analysis of the raw network traffic, correlation and visualisation of the generated high level information and that there is still scope for further research in this area accompanied by application of techniques such as artificial intelligence and advanced analytics.

Merkle (2008) proposed the concept of implementing intelligence into network forensic analysis leading to the formation of an automated tool, making use of computational intelligence. The research describes the idea of integrating the tools used in different stages of a forensic investigation in to a single system utilizing computational intelligence in order to reduce human interaction. The model used the existing search techniques used for network forensic analysis and combined them with the computational intelligence techniques in order to increase the efficiency of the entire system. Computational intelligence was utilised in the data collection stage. The data set was created by implementing evolutionary computational algorithms on attacker systems generating variations of commonly known attacks against a honeynet. Processes such as analysing the alert data manually which consumed more time and are error-prone were the ones chosen for automation. In a later stage, these alert data, depending on their characteristics and their relationship to the hypothesis generated in an early stage, were organized into clusters by making use of evolutionary computation.

Another work used the application of fuzzy sets into forensic investigation system in order to derive a set of if-then rules reducing the effort of forensic analysis with the aim to overcome two of the existing constraints in forensic data analysis – accuracy and the ability to understand the output easily by investigators (Stoffel *et al.*, 2010). The methodology used in their work was to divide the raw forensic data into groups, called clusters. Then membership functions were extracted from those data fuzzy inference systems were created. The data used for testing were of conventional crime incidents of robberies and residential burglaries. The proposed methodology was tested against an artificially created datasets with some hidden internal structures and the experiments resulted in identifying the hidden structures and by not discovering any structures that do not exist in the original dataset with a satisfactory level of accuracy

Another paper proposed the use of AI techniques for offline intrusion analysis by aiming to rank the input features in order to reduce the inputs received in the collection and detection phases. Proposed work attempted using artificial neural networks (ANN) and support vector machines (SVM) techniques on data taken from MIT's Lincoln Labs which was developed for offline intrusion detection system evaluations by DARPA in 1999 and resulted in concluding that SVM techniques can perform better than ANNs in scalability, training time and prediction accuracy (Mukkamala, 2003). It points out that making use of artificial intelligent techniques can increase the performance level of network forensic investigation by reducing the volume of collected data by eliminating the unimportant events.

While network forensics is an essential part of the investigation, there is another component of the organisational network called Security Information Event Management (SIEM), which acts as a core tool in detecting real-time threats and performing log management for forensic investigation, which has objectives similar to that of network forensics. SIEM is a vital part that interconnects with other components of the organisational infrastructure to perform real-time threat detection, acting as a proactive system and trying to achieve similar analysis goals as network forensics. Recent research in this field proposes the adaptation of security analytics and threat intelligence from external sources in order to make SIEM systems more dynamic and preventive. In order to increase the efficiency in the analysis and correlation phases of the investigation, network forensics also need to adapt advanced analytics and intelligence based techniques. Considering the contributions offered by the AI techniques in various other fields of computing and the proposals made about AI, it gives a scope for the application of AI techniques into the field of network forensics.

NETWORK-LEVEL ANALYSIS OF USER APPLICATION DATA

An essential aim for a forensic investigator is to determine how a crime was undertaken – in order to identify the actors involved, how the crime unfolded and to develop a chronology of the incident. As argued by the literature review, the ability to do this based upon network traffic is extremely challenging and very time consuming. At present, only information about what services were accessed, timestamps and volumes of traffic can be determined – in addition to some object-based data carving. It is suggested that providing the investigator with a wider range of information about the nature of the service access (as illustrated in Table 1), could provide valuable insights into the nature and execution of the crime. This section presents the results of an experiment to determine the viability of extracting user-interactions from network meta-data. The experiment was based upon three key services:

1. Web Surfing – BBC News website
2. Voice/IM Chats – Skype
3. Social Networking – Facebook

Table 1: Examples of selected Internet-enabled services and user actions

Services	User Actions
Cloud Storage	Edit, share, upload, download, remove
Emails	Compose, attachment, read, delete
Information gathering	Information browsing, watch video clips, listen to online clips
Instant messenger	Chat, voice call, video conference, file transfer
Online banking	View bank statement, money transfer
Social networking	Posting, viewing wall, uploading photos/videos, chatting, comment

Web Surfing

To analyse what user interactions are possible with general web surfing, it was decided to focus upon the BBC website as its representative of an information portal (and a particularly popular one). It is also an example of a non-encrypted site (in comparison to the other two services which are being analysed). As the service is unencrypted it is possible to analyse the traffic at TCP flow level rather than packet level. Being a dynamic (rather than simple website) each request made to the site generated a number of TCP connections but it is possible to identify specific user interactions. Figure 1 illustrates a user loading a page.

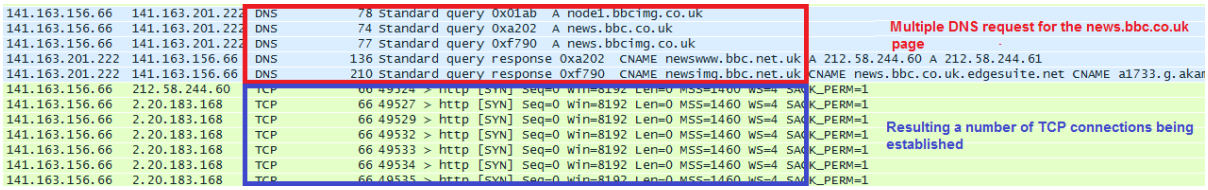


Figure 1: Surfing BBC News

It is possible to derive a number of user interaction signals from web surfing BBC news that provides more information than simply that a suspect/victim accessed the site (as illustrated in Table 2). It is possible to understand how many pages they accessed – whether this was merely a home page or a new story – how long they spent on each page and on the site overall. It is also possible to identify whether they watched any video content.

Table 2: User Interactions derived from BBC News

Actions	Protocol	Destination Port	Total length (bytes)	Number of packets	Directions
View page	TCP	Random port	Various	Various	server >Client
View video	TCP	Random port	MTU (Almost)	Many	server >Client

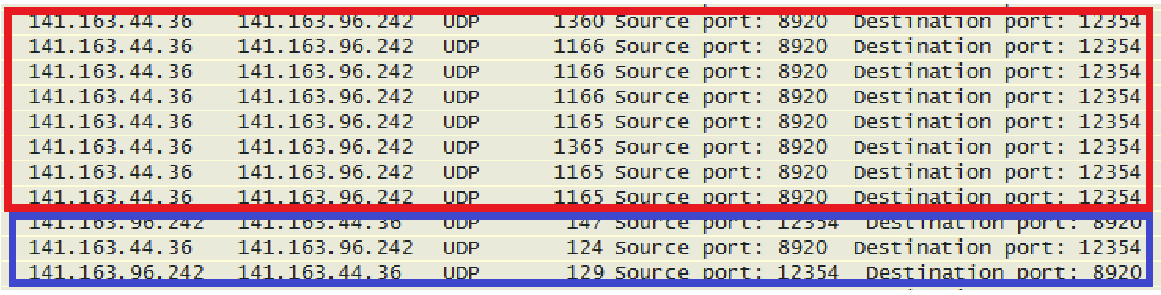
Voice/IM Chats

Skype was chosen for the voice and IM chatting applications as it is amongst the most popular. Skype based traffic is encrypted but an analysis of the network traces – at packet rather than flow level does reveal a number of user interactions. A number of user activities were tested against their corresponding network metadata signals, including chatting, video conferencing and file sharing. The analysis shows that chatting is handled directly from the client to the Skype server (IP 157.56.192.26 via TCP port 443) – as illustrated in Figure 2. The baseline for sending characters was 794 bytes on the network. For example, a 19-character sentence the corresponding network signal was one 813-byte frame. Upon repeating this experiment, it was noticed that the baseline did vary between users and thus a threshold will need to be identified on a per-user basis in order to identify this interaction.

Figure 2: IM via Skype

Both the video-conference and file sharing were set up directly between two clients via UDP ports (i.e. not via the Skype server). For the video conference, one client was sending video frames with larger size packets (e.g.

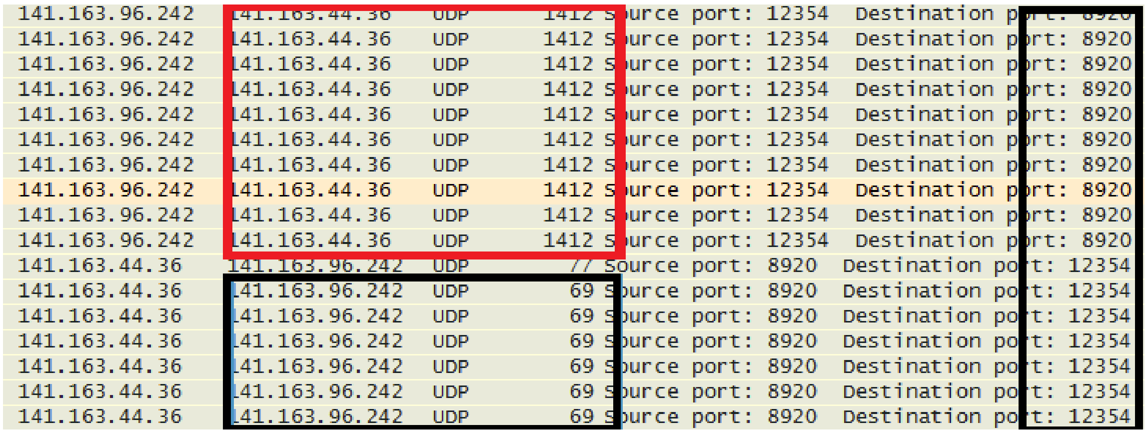
1166-1360 bytes) while the other was sending audio in smaller packets (e.g. 129-149 bytes) as only the former client had the camera turned on while the latter did not (as illustrated in Figure 3).



141.163.44.36	141.163.96.242	UDP	1360	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1166	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1166	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1166	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1165	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1365	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1165	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	1165	Source port: 8920	Destination port: 12354
141.163.96.242	141.163.44.36	UDP	147	Source port: 12354	Destination port: 8920
141.163.44.36	141.163.96.242	UDP	124	Source port: 8920	Destination port: 12354
141.163.96.242	141.163.44.36	UDP	129	Source port: 12354	Destination port: 8920

Figure 3: Video conferencing via Skype

Regarding file sharing, an analysis of the subsequent network traces identify (as illustrated in Figure 4) that packets sizes reflexed the maximum packet size that the network can handle (the MTU) (i.e. 1412 bytes in this example) and these were sent by the sender while receiving little traffic from the receiver (merely replying with acknowledgments) (i.e. 69 bytes Ethernet frames). Furthermore, both traffic flows for video-conferencing and file sharing was sent in a continuous manner - thus would manifest themselves as a series of packets lasting more than a few seconds.



141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.96.242	141.163.44.36	UDP	1412	Source port: 12354	Destination port: 8920
141.163.44.36	141.163.96.242	UDP	77	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354
141.163.44.36	141.163.96.242	UDP	69	Source port: 8920	Destination port: 12354

Figure 4: File Sharing via Skype

Based up these observations it is possible to derived signatures for the network traffic that would identify the user interactions within Skype. As illustrated in Table 3, even though the service is completely encrypted it is still possible to identify a range of interactions – providing information to an investigator about how many times the suspect/victim uses skype for instant messaging, video/audio calling and file uploads.

Table 3: User Interactions Derived from Skype

Actions	**Protocol**	**Destination Port**	**Frame length (bytes)**	**Number of packets**	**Directions**
Chat	TCP	443	794+	1	Client >server
File sharing	UDP	Random port	MTU (Almost)	Many	Sending client > receiving client
File sharing	UDP	Random port	69	Many	Receiving client > Sending client
Video conference	UDP	Random port	1165-1365	Many	Both clients
Audio call	UDP	Random port	129-147	Many	Both clients
Idle	TCP	443	572	1	Client >server
Click on contacts	TCP	443	731	1	Client >server

Social Networking

Facebook was chosen for the social network analysis. A number of user activities were performed and compared against their corresponding network signals. The network signals that are created when accessing the site are

large in number and also encrypted which results in a more complex analysis. With more dynamic and complex web services, it is clear a significant degree of additional traffic is generated – which serves to complicate the analysis. For example, Facebook has an idle signal that is sent periodically – this is functionality that helps to ensure the webpage is up to date. Without care, this signal could be misrepresented as a user interaction.

When the typing activity started in the chatting dialog box, a network signal with a total of 1502 bytes (i.e. 1434+68) was sent from client to the Facebook server; the same pattern also occurred directly after a message being sent. Moreover, the baseline for chatting in Facebook is a total of 2,625 bytes (i.e. 1434+1191). For example, when a 4-character word is sent to the server, a total of 2,629 bytes appeared on the network. This pattern is illustrated in the analysis presented in Figure 5.

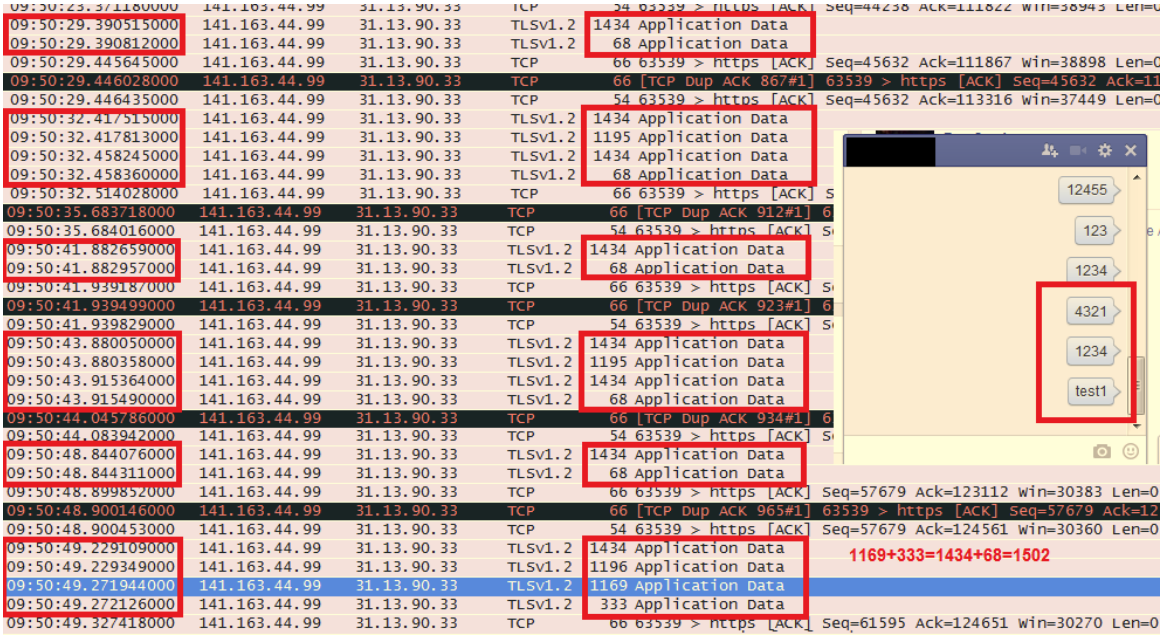


Figure 5: Chatting on Facebook

An examination of the photo uploading activity (as illustrated in Figure 6), shows a stream of almost full size Ethernet frames (i.e. the MTU which in this example 1434 bytes) were sent from the client to the Facebook server while the Facebook server simply acknowledged the receiving of the data (indicated by TCP ACK flag).

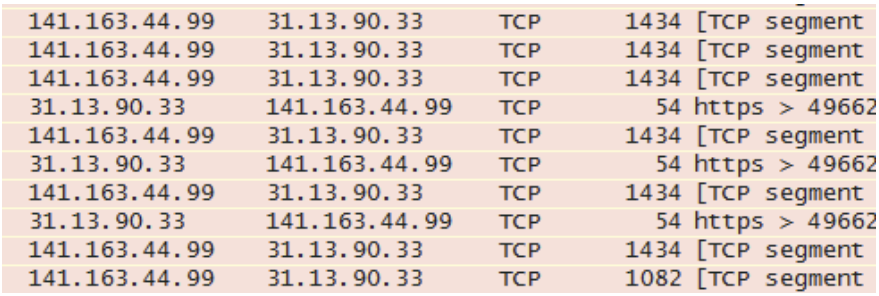


Figure 6: Photo uploading on Facebook

Based upon this signals analysis, the Table 4 presents a series of user interactions and the subsequent information required to detect the interaction from network traffic.

Table 4: User Interactions Derived from Facebook

Actions	**Protocol**	**Destination Port**	**total length (bytes)**	**Number of packets**	**Directions**
Chat	TCP	443	2,625+	2	Client >server
Typing	TCP	443	1502	2	Client >server
File uploading	TCP	443	MTU (Almost)	Many	Client >server
Idle	TCP	443	149	2	Client >server
Page load / viewing wall	TCP	Random port	Various	Various	Server >client

UO-NFAT FRAMEWORK

A network forensic analysis tool needs to develop the ability to operate in a similar fashion to computer forensic case management tools – i.e. provide a basis for abstracting/parsing low-level data into higher-level information that aids in easy analysis and interpretation by a forensic examiner. This includes the ability to identify and reconstruct protocols, reduce non relevant traffic, identify and extract objects (e.g. images, documents), reconstruct user events and correlate activities and data. The purpose of having such a NFAT is to reduce the cost, the time spent on the investigation and the cognitive load placed on the investigator in terms of their ability to correlate evidence.

The User-Oriented (UO) NFAT illustrated in Figure 7 seeks to provide a robust, extensible and investigator-friendly tool that provides the necessary core analysis functionality and the additional case management tasks such as reporting. Its focus is placed upon cyber and computer-assisted crimes that involve people – i.e. insider misuse, hacking and IP theft – rather than on the identification and analysis of malware. The central component of the framework, *UO-NFAT Manager*, acts as the case manager and central point from which analysis of the traffic can take place - interconnecting different modules and analysis tools. It is the UO-NFAT Manager that the investigator interacts with in order to provide initial case intelligence (e.g. nature of the crime, suspect/victim information) upon which analysis can subsequently focus to provide more detailed information. For example, this can help in phases such as pre-processing, protocol analysis, pattern/keyword searching and data carving. Having a specific set of case intelligence can contribute towards reducing the volume of data to be analysed.

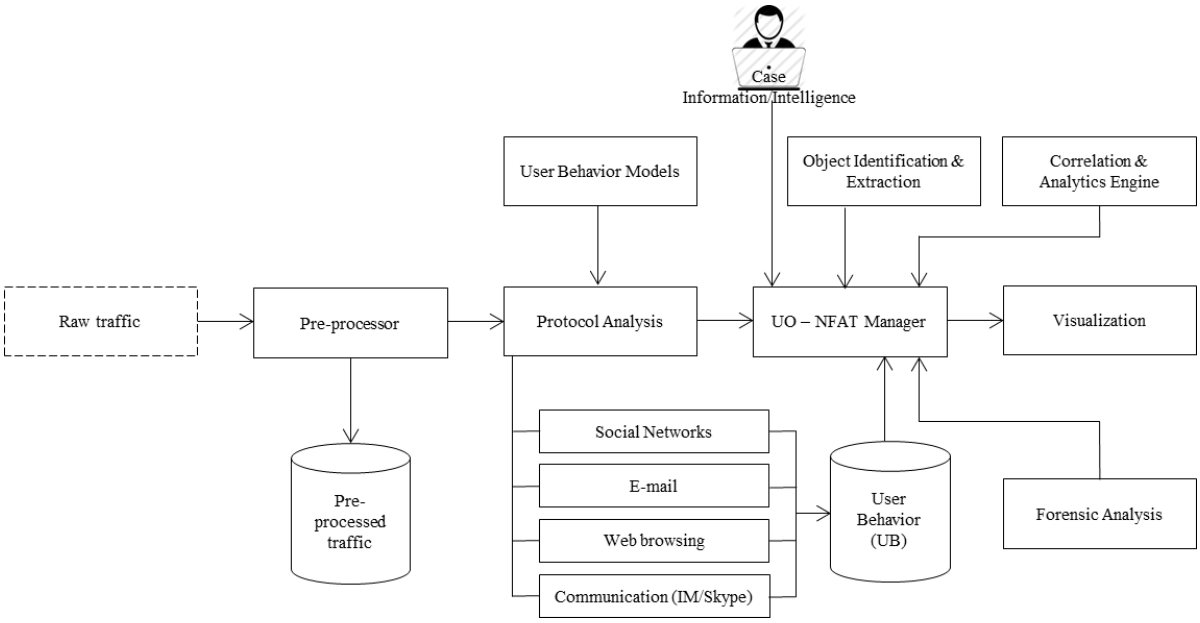


Figure 7: User-Oriented Network Forensic Analyser Design

The *Pre-Processor* module takes the raw traffic as its input and the purpose of this module is to reduce the amount of network data to be analysed by eliminating any noise. Considering the nature of the investigation, particular subsets of network protocols can be removed from the analysis – for example, when investigating what user activity is present, all protocols involved in machine-to-machine communication such as DHCP and ICMP can be removed. The pre-processor will also abstract the data out to TCP flows from the packet level to aid in reducing the complexity, noise and volume of data to be analysed. Once completed, the pre-processed traffic is stored in a database and is forwarded to the protocol analysis module.

The *Protocol Analysis* segment performs the detailed examination of the pre-processed traffic to generate the high-level user directed behavioural information in order to assist an investigator in appreciating what the user(s) are doing within online services. All abstracted user interactions are subsequently stored in the *User Behaviour* database. The *Object Identification & Extraction* module which operates on the information stored in the 'user behaviour' database and pre-processed data to identify and extract any high level objects (such as images, documents, PDFs, emails, instant message chats) and correlate these with the derived user interactions. The outcome of this process is to provide an investigator with an overview of the activities undertaken by users and direct access to data being transferred.

The *Forensic Analysis* module attempts to incorporate some features exhibited by the established computer forensic tools such as hashing (for identifying file signatures, known and notable files), data carving, regular

expressions and keyword searching. The *Correlation & Analytics* engine uses data correlation and analytic techniques in order to provide further investigation and analysis between user activities, data objects and data flows. For example, the relationship between different IP addresses those are responsible for the suspicious traffic and movement of data.

Based on the all the obtained information, the *Visualization* module presents the investigated user activities in a visual and an interactive manner. An example of the user interface dashboard is shown in Figure 8. The tool provides an interface where investigators get access to the user interactions and summary information in a chronological manner (top window). Selection of any of the interactions, results in the data objects being loaded and thus viewable by the forensic examiner (middle right window). For integrity and bookmarking purposes, when the investigator selects an object, the associated network traffic, which this data is derived from, is then highlighted (in the bottom window) – this ensures all evidence is directly mapped back to the raw evidence. The interface also provides the investigator with a range of filtering options based upon protocols, services and activities (middle left window).

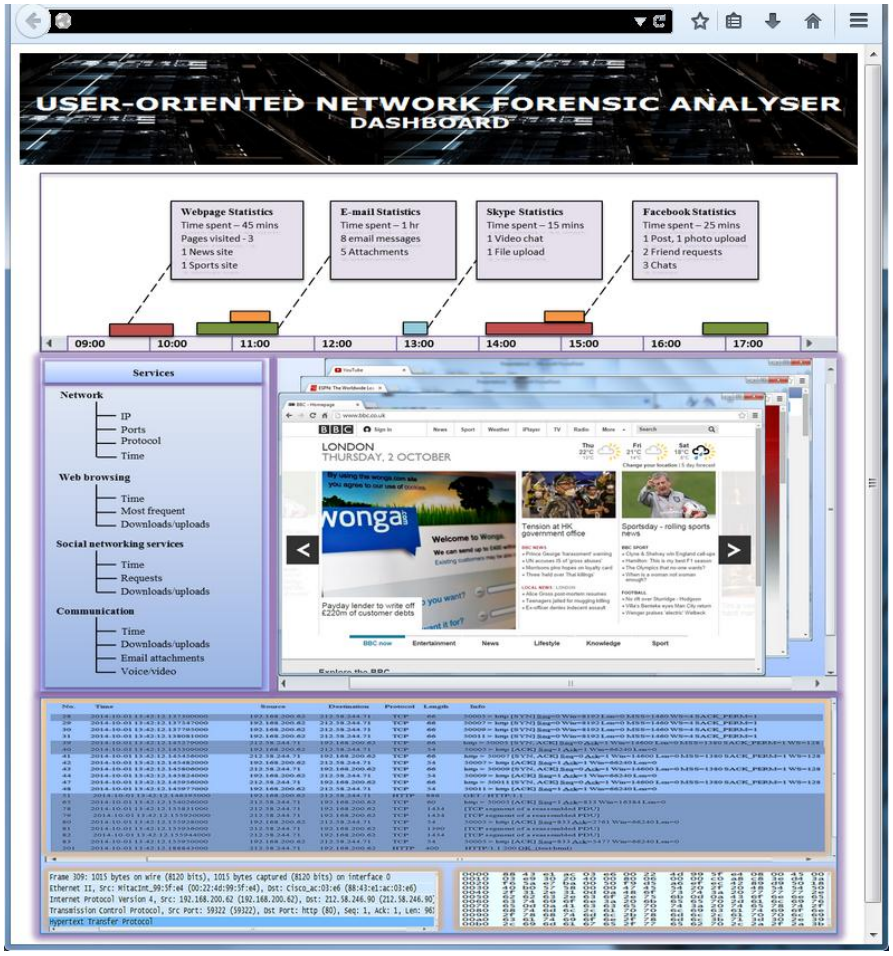


Figure 8: User-Oriented Network Forensic Analyser Dashboard

CONCLUSION AND FUTURE WORK

The paper addresses the need for network forensics, giving specific importance to the requirement of generating high-level information from the raw network traffic and applying correlation techniques to better appreciate the relationship between artefacts. The paper has demonstrated that it is possible to derive user interactions from online services from low-level network metadata and has subsequently proposed a tool then proceeds to analyse and visualise these in order to reduce the cognitive load upon the investigator and make it easier to identify and map an incident.

Our future work seeks to develop an empirical basis for extracting user interactions from a complete range of application services, and to develop the UO-NFAT tool that will incorporate this into a functional and usable forensic tool. Given the processing and storage-heavy nature of network forensics, more research will be

conducted to investigate how to handle and process large volumes of traffic and look to identify relevant technology platforms that this can be deployed to.

REFRENCES

AccessData Corp. 'Forensic Toolkit [Online] http://accessdata.com/solutions/digital-forensics/forensic-toolkit-ftk [November, 2014]

AccessData Corp. 'SilentRunner Sentinel' [Online] http://accessdata.com/solutions/cybersecurity/silentrunner-sentinel [July, 2013]

Casey, E. (2004) 'Network traffic as a source of evidence: tool strengths, weaknesses and future needs' *Digital Investigation,* 1(1), 28-43

Chowdhury, T. and Vidalis, S. (2012) 'Collecting evidence from large-scale heterogeneous virtual computing infrastructures using Website Capture'. *2012 Third International Conference on Emerging Intelligent Data and Technologies*, 211-217

Cisco "Cisco Visual Networking Index: Forecast and Methodology, 2013-2018", [online], http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html [November 2014]

Cohen, M. I. (2008) 'PyFlag – An advanced network forensic framework'. *Digital Investigation: The International Journal of Digital Forensics & Incident Response,* **5**, 112-120

DFRWS 'A Road Map for Digital Forensic Research: Report from the first Digital Forensic Research Workshop (DFRWS) – August, 2001' [Online] http://www.dfrws.org/2001/dfrws-rm-final.pdf [November, 2014]

Fahmy, S., Nasir, A. and Shamsuddin, N. (2012) 'Wireless Network Attack: Raising the Awareness of Kampung WiFi Residents'. *2012 International Conference on Computer and Information Science (ICCIS)*, **2**, 736-740

Garfinkel, S. (2007) 'Anti-Forensics: Technique, Detection and Countermeasures'. *2nd International Conference on i-Warfare and Security*, 77-84

Garfinkel, S L. (2010) 'Digital Forensics Research: The Next 10 Years'. *Digital Investigation*, **7**, 64-73

ISO 'ISO/IEC 27037:2012 – Information Technology – Security Techniques – Guidelines for identification, collection, acquisition and preservation of digital evidence' [Online] https://www.iso.org/obp/ui/#iso:std:iso-iec:27037:ed-1:v1:en [November, 2014]

ITU-T 'Big Data: Big today, normal tomorrow – ITU-T Technology Watch Report 2013' [Online] http://unstats.un.org/unsd/trade/events/2014/Beijing/documents/other/ITU%20-%20Big%20Data%20today,%20normal%20tomorow.pdf [November, 2014]

Lyonesse Software 'Iris Network Traffic Analyser' [Online] http://www.lyonware.co.uk/Iris.htm [February, 2013]

McGuire, M. and Dowling, S. (2013) 'Cybercrime: A review of the evidence – Summary of key findings and implications – Home Office Research Report 75' [Online] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/246749/horr75-summary.pdf [November, 2014]

Merkle, L.D. (2008) 'Automated Network Forensics'. *Proceedings of the conference on genetic and evolutionary computation (GECCO 2008)*, 1929-1932

Mukkamala, S. and Hung, A.W. (2003) 'Identifying Significant Features for Network Forensic Analysis using Artificial Intelligence Techniques'. *International Journal of Digital Evidence,* **1**(4), 1-17

NETRESEC 'NetworkMiner' [Online] http://www.netresec.com/?page=NetworkMiner [July, 2013]

Netscout 'nGenius InfiniStream Appliance' [Online] http://www.netscout.com/library/Data%20sheets/NetScout_DS_nGenius_InfiniStream_Appliance_SP.pdf [July, 2013]

NIKSUN 'NetDetector Alpine' [Online] https://www.niksun.com/product.php?id=4 [September, 2013]

NIKSUN ‘NetIntercept’ [Online] https://www.niksun.com/collateral/NIKSUNDatasheet_NetIntercept_1010.pdf [September, 2013]

Pajek, P. and Pimenidis, E. (2009) ‘Computer Anti-Forensics Methods and Their Impact on Computer Forensic Investigation’. *Global Secuirty, Safety and Sustainability Communications in Computer and Information Science*, 45, 145-155

Pilli, E S., Joshi, R C. and Niyogi, R. (2010) ‘Network Forensic Frameworks: Survey and research challenges’. *Digital Investigation,* **7**, 14-27

RSA ‘RSA NetWitness Overview’ [Online] http://uk.emc.com/collateral/data-sheet/rsa-netwitness-nextgen.pdf [September, 2013]

Solera Networks ‘DeepSee 5150 – Comprehensive Network Forensics Appliance’ [Online] http://www.soleranetworks.co.jp/resources/datasheet5150_web.pdf [February, 2014]

Stoffel, K., Cotofrei, P. and Han, D. (2010) ‘Fuzzy Methods for Forensic Data Analysis’. *2010 International Conference of Soft Computing and Pattern Recognition (SoCPar)*, 23-28

Tamos ‘NetResident – Network Content Monitoring’ [Online] http://www.tamos.com/docs/nr_datasheet.pdf [February, 2014]

WildPackets ‘OmniPeek Network Analyzer’ [Online] http://www.wildpackets.com/elements/omnipeek/OmniPeek_Network_Analyzer_datasheet.pdf [February, 2014]

Wireshark ‘Wireshark User’s Guide’ [Online] https://www.wireshark.org/docs/wsug_html_chunked/ [September 2013]

Xplico ‘Xplico Features’ [Online] http://www.xplico.org/about [September, 2013]