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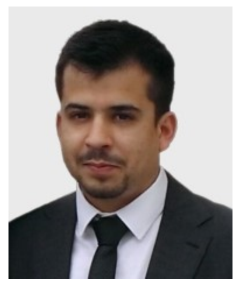

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Development of a Cyber-Threat Intelligence-Sharing Model from Big Data Sources

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Abstract: *As data in cyberspace continues to grow because of the ubiquity of Information Communication Technologies (ICT), it is becoming challenging to obtain context-aware, actionable information from Big Data to timely detect and respond to cyberattacks that are increasing in severity, complexity, and frequency. In fact, cybercriminals are developing and sharing advanced techniques for their cyber espionage, reconnaissance missions, and ultimately devastating attacks. In order to reduce cybersecurity risks and strengthen cyber resilience, strategic cybersecurity information-sharing is a necessity. This article discusses one way of handling large volumes of unstructured data that have been generated by multiple sources across different sectors into a cyber-threat intelligence-sharing model.*

Keywords: *Cybersecurity, Cyber-threat Intelligence, Cyber Intelligence, Crowdsourcing, Big Data, Web Security, Vulnerabilities*

Introduction

Public sectors, private sectors, and individuals continue to rely on the Internet for effective information sharing and communication. Key to the effectiveness of the Internet for these three stakeholders is the exponential growth in the ubiquity of Information Communications Technologies (ICT), with Gartner reporting that the growth in the number of ICT devices connected to the Internet will grow by 35% in 2016 and will reach a total of 6.4 billion connected devices in 2020 (Meulen 2015). The sheer large number of ICT devices on the Internet has become instrumental in enabling these key stakeholders to be prosumers—that is, both producers and consumers of large information on the Internet. This has inadvertently led to what is commonly called Big Data: “extremely massive and highly complex data sets of information” that are continuously increasing in volume, velocity, and variety (Khan *et al.* 2014; Zikopoulos & Eaton 2011). Although Big Data presents various opportunities for organisations (Kaisler *et al*. 2013), it also introduces numerous challenges, such as difficulties in collecting, storing, processing, and analysing all this data in order to act upon it or extract value in a timely manner (Katal, Wazid & Goudar 2013; Zikopoulos & Eaton 2011). The timely processing of Big Data is necessary to provide the context-aware, actionable information that is required to remedy vulnerabilities affecting a large number ICT devices connected to the Internet, remedies without which a major threat is presented to the users of these ICT devices in the form of cybercrimes.

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In cyberspace, threats and attacks continue to increase in number and complexities (Mtsweni *et al*. 2016). As such, cybersecurity threat intelligence is gaining prominence, mainly to enable users to collect Big Data that will allow them to recognize, understand, and protect themselves against sophisticated cyber adversaries and vulnerabilities that are reported on a daily basis. However, organisations are also finding it increasingly challenging to adequately tap into security-related Big Data and implement appropriate solutions for the exposed vulnerabilities or imminent threats. The main reason for this is that most organisations still operate in isolation when it comes to gathering cybersecurity intelligence. However, it is apparent that no one organisation can act on all the security-related Big Data alone.

Notably, in the developed world, large organisations are already collecting and sharing threat intelligence in order to protect themselves from emerging threats and attacks (Brown, Gommers & Serrano 2015). Powerful governments, such as in the United States and United Kingdom, are already enacting legislation that attempts to encourage cybersecurity information sharing between the government and private sectors (Fransen, Smulders & Kerkdijk 2015; Ring 2014). At the same time, large organisations across the world already have security teams gathering large security datasets in order to understand the current threats and protect themselves from imminent cyberattacks. Computer Incidents Response Teams (CSIRTs) are also common in many countries for receiving, reviewing, and responding to computer security incident reports and activities (CERT.org 2016).

Nevertheless, cybersecurity threat intelligence or information sharing is still emerging and possibly immature; thus, many nations, particularly developing nations, are lagging behind. In addition, relevant use cases and models that could encourage cybersecurity information sharing are limited. Existing solutions for sharing cybersecurity information are mostly commercial, and most lack the necessary semantics, intelligence, and visualizations necessary for sharing actionable, reliable, context-aware, and timely information. CSIRTs are mostly reactive and do not have foresight capabilities; moreover, they tend to focus on a multitude of vulnerabilities and incidents, which are not necessarily relevant to every organisation within a specific domain. This article presents a preliminary cyber-threat intelligence-sharing model that could be used by collaborating and trusted stakeholders to share cybersecurity information that might make it possible to limit and/or prevent cyberattacks more quickly.

Background

In the fast-moving domain of cybersecurity, "receiving the right information at the right time" is vital in reducing security risks, deterring attackers, and improving the security posture of an organisation (Goodwin & Nicholas 2015). Hence, making effective use of cyber-threat intelligence is an important component of any organisation's cybersecurity strategy. In government and military environments, intelligence is a well-understood concept and involves the collection, analysis, and interpretation of information for battlespace awareness (Waltz 1998) and, eventually, for decision-making purposes (for example, whether to defend or attack). This concept is also gaining ground within the cybersecurity space, chiefly because software vulnerabilities, threats, and attacks are becoming more complex, severe, and dynamic. Threats are changing on a daily basis and so should the solutions. Indeed, intelligence and continuous awareness of software vulnerabilities, cyber threats, and attacks that face individuals and organisations on a daily basis are essential for mission accomplishment in cyberspace (Polancich 2014).

Before defining threat intelligence, this article makes a clear distinction between security information and cyber-threat intelligence. **Table 1**, below, highlights some of the differences. As may be noted in **Table 1**, ordinary security information, such as that found in common-vulnerabilities' databases, might be unstructured and might make it a challenge for organisations to act upon information in a timely manner. In essence, Big Data can be classified as a large set of raw information, whereas cybersecurity intelligence is information that is possibly structured, relevant, actionable, and well-timed *and* that enables organisations to achieve business goals (for example, to secure information assets).

Security Information	Cyber-Threat Intelligence
Is structured, unstructured, raw (general), unfiltered information.	Is structured, relevant, sorted, and processed information.
Is aggregated from virtually every source.	Is reliably aggregated and correlated for accuracy.
May be true, false, misleading, incomplete, relevant, or irrelevant.	Is accurate, timely, complete (as possible), assessed for relevancy.
Is not actionable.	Is actionable.

Table 1: Security information vs cyber-threat intelligence (Mishra 2014)

Although cybersecurity intelligence is an emerging discipline, it is fairly defined (Brown, Gommers & Serrano 2015; Ring 2014). It is often referred to as threat intelligence, intelligence-driven information security, cyber intelligence, or cyber-threat intelligence (Eom 2014; Ring 2014; Mishra 2014; Goodwin & Nicholas 2015). For the purposes of this discussion, these terminologies are used interchangeably to loosely refer to the collection and analysis of cybersecurity vulnerabilities, threats, incidents, and Indicators of Compromise (IOCs), such as malicious IPs and URLS, tactics, techniques and procedures (TTPs), and recent attacks.

According to Eom (2014), "cyber intelligence refers to the collection, processing, analysis, integration, evaluation, and interpretation of data concerning hostile cyber organisation, cyber forces capabilities, network systems, hardware, software, threats and vulnerabilities". In addition, Eom also defines threat intelligence as

> evidence-based knowledge, including context mechanisms, indicators and actionable advice about an existing or emerging menace or hazard to assets that can be used to inform decisions regarding the subject's response to that menace or hazard. (2014)

It is important to highlight the fact that threat intelligence is about the discovery of vulnerabilities and threats before attacks are performed. Hence, Farnham (2013) maintains that intelligence is actionable information. Threat intelligence could also be classified as strategic, operational, or tactical (Eom 2014). For the current discussion, the focus is on tactical intelligence, which deals with information such as incidents, threats, vulnerabilities, TTPs, and IOCs (Goodwin & Nicholas 2015).

According to Ring (2014), threat intelligence is an expensive exercise, which only a few big organisations can afford to invest in on their own. As such, other small organisations are priced out of the threat-intelligence market. Nevertheless, different types of threat-intelligence collection mechanisms are emerging, including Open Source Intelligence, Cyber Space Intelligence, and Human Intelligence.

At the same time, there are a variety of cybersecurity threat-intelligence sources, mainly classified as internal or external and categorized as public or private. Presently, the manner in which threat intelligence is gathered and acted upon is solely based on individual organisations. The challenge with this approach (the lack of collaborations amongst organisations and governments) is well recognized (Ring 2014). The insights shared in this paper contribute to this space of collaborative and coordinated tactical cybersecurity threat intelligence. The authors posit that securing oneself against complex cybersecurity threats and attacks calls for a shared and a coordinated approach that involves a number of stakeholders, such as the owners, developers, and users of the systems that are susceptible to cyberattacks.

There are different approaches that could be adopted to exchange cybersecurity information. According to Goodwin & Nicholas (2015), some of them could be 1) voluntary exchange, 2) mandatory disclosure, 3) formalized exchange, 4) security-clearance-based exchange, 5) trust-based exchange, and 6) ad-hoc exchange. For the purposes of this article, trust-based, ad-hoc, and voluntary exchange approaches are adopted. These approaches will be further elaborated upon in subsequent sections.

The Rise of Big Data

The importance of Big Data in the cybersecurity space cannot be overemphasized. In countries such as the United States, it is even viewed as a national challenge and priority, along with health care and national security. Big Data presents a number of interesting challenges for cyber intelligence—for example, quality of data, privacy, and security (Katal, Wazid & Goudar 2013). These challenges are compounded by the fact that Big Data is generated on a daily basis through various media. This fact makes it impossible for one organisation to store and to process in a timely manner such data for decision-making purposes. Indicators of Compromise (IOCs) (for example, cyber threats, vulnerabilities, viruses, and malicious sites) contribute to the scale of Big Data. These IOCs are released on a daily basis by individuals, as well as by private and public organisations. However, organisations are unable to act on these IOCs in a timely manner for a number of reasons. One of these reasons is that organisations still rely heavily on traditional systems. Traditional systems suffer when it comes to dealing with Big Data; as such, new ways of dealing with Big Data, especially within the context of cybersecurity threat intelligence, are needed.

Cybersecurity Threat-intelligence Exchange Platforms

As touched on in the introduction, there are a couple of commercial and open-source threat-intelligence platforms that exist on the Web and in other closed environments. These platforms vary in terms of their features and target market. The following sections present a systematic literature review of these platforms and provide context for the combined platform developed by the authors as a Proof of Concept (POC).

- **Malware Information Sharing Platform (MISP)**
  MISP is a platform for sharing, storing, and correlating Indicators of Compromises of targeted attacks by allowing organisations to share information about malware and their indicators (CIRCL 2016). MISP is a web-based tool using a REST API to send and receive data. The MISP allows for storing of technical and non-technical information about malware and attacks, for tracing correlations between malwares, for storing data in a structured format, for exporting and importing in various formats, and for data-sharing with other parties and trust groups using MISP and STIX support to export data in STIX format (Barnum 2014).

- **AbuseHelper**
  This is an open-source project that is used to automatically process incident notifications. This tool is developed for Computer Emergency Response Teams (CERTs) and Internet Service Providers (ISPs) to help them in their daily jobs of following and treating a wide range of high-volume information sources (AbuseHelper 2011).

- **IntelMQ**
  IntelMQ is a solution that was designed for CERTS to collect and process security feeds, pastebins, and tweets using a message queue protocol. Its main goal is to give incident responders an easy way to collect and process threat intelligence to improve the incident-handling processes of CERTS (IntelMQ 2015).

- **Cyber Threat XChange (CTX)**
  The Cyber Threat XChange (CTX) is a component of the HITRUST Alliance Cyber Threat Intelligence and Incident Coordination Centre (C3), which was created to detect and respond to cyber threats that are targeting the healthcare industry (HITRUSTAlliance 2016). CTX collects and analyses the cyber threats and distributes actionable indicators in electronically consumable formats that organisations can utilize to improve their cyber defences (HITRUSTAlliance 2016).

- **Open Threat Exchange (OTX)**
  This platform is an open-threat information-sharing and information-analysis network that is created to put effective security measures within the reach of all organisations (AlienVault 2014). OTX provides real-time, actionable information. The information shared is anonymized and shared with the AlienVault community.

- **Soltra**
  Soltra is a commercial cyber-threat intelligence-sharing platform. It integrates well with various other systems and is capable of pulling security data from disparate sources. It de-duplicates the data and routes intelligence to users, devices, or communities in real time (Soltra 2016).

- **Collaborative Research Into Threats (CRITS)**
  CRITS is an open-source malware and threat repository that uses other available open-source software to enable users to create incidents and share them with others (Goffin 2014). It can also be used by analysts and security experts to defend against malware and

cyber threats. CRITS data is converted to CybOX objects, packaged within STIX documents. As such, CRITS uses STIX as a common standard to convey the full range of cyber-threat information.

- **Trusted Automated eXchange of Indicator Information (TAXII)**
  TAXII is the preferred method of exchanging information represented using the STIX language (MITRECorporation 2016). CRITS can also be accessed locally, remotely, or via custom APIs. This article explores all the different access mechanisms as part of testing the feasibility of the sharing model within a distributed environment. Since CRITS is open source and allows for integration with other systems using open-source APIs, it can also be extended, which is essential for adapting the sharing model to the needs of different stakeholders.

Cybersecurity-threat Intelligence-sharing Model

Today, there is continuous access to instant information about virtually everything in the always-connected world. Personal and organisational information is easily accessible online using multiple-platforms, including Open Source Intelligence (OSINT). A common maxim states that 'information is power'; and in the defence environment, information is a critical element of power. As previously mentioned, receiving the right information on time can be the difference between a successful and unsuccessful cyberattack (Goodwin & Nicholas 2015).

In cyberwarfare and information-warfare environments, information operations in their various forms can be used to gain information and decision superiority over an adversary. In cybersecurity, the maleficent actors mostly rely on systems' vulnerabilities and threat information to breach or attack the target of interest. Thus, to mount a defence against malicious actors, cybercrimes, or cyberattacks, actionable information about the adversaries' systems' vulnerabilities, emerging cybersecurity threats, and current cyberattacks cannot be ignored.

Because most cyber ills are conducted using publicly available information by collaborating malicious actors, cyber defence stakeholders cannot continue to operate in isolation in their efforts to defend and protect cyberspace. The stakeholders in the defence environment need to start sharing cybersecurity threat intelligence in an inherently collaborative endeavour requiring cooperation among members of the cybersecurity community. Since sharing of threat intelligence can also occur at strategic, tactical, and operational levels, it is important that an appropriate sharing model is formulated and agreed upon by those involved.

First, the model needs to focus on the involved stakeholders' understanding of the operating environments. According to ThreatView (2016), if an organisation does not understand its assets, infrastructure, personnel, and business operations, it cannot know if it is presenting opportunities to malicious actors. Moreover, the information that needs to be shared amongst the stakeholders in some environments must be at a level higher than cyber information, which is mostly useful in reactive operations (for example, cyber incidents, observables, and Indicators of Compromise). The cybersecurity threat intelligence involved should be contextual and actionable, *and* should enable proactive and predictive responses to cyberattacks and cybercrimes. Furthermore, it should be possible to provide operational information about threat actors, their campaigns, cyber behaviours, and TTPs (Tools, Techniques, and Procedures). As such, information sharing between various stakeholders within an environment could prove vital in threat intelligence.

In some environments, there is a need to seek to share information and coordinate with industry partners in an integrated manner to promote situational and battlespace awareness. For example, if a third-party partner learns of malicious cyber activities that could affect important networks and systems, the sharing model could provide guidelines for the manner by which this threat information can be shared quickly enough to avoid the attack or reduce the risk. Above the sharing of threat information, lessons learned and cybersecurity best-practices can also be shared by the stakeholders to improve the resiliency of cyberspace. The following section discusses the research approach used to answer the questions put forward in the introduction section.

Research Approach

The research presented in this article followed an experimental approach as described by the Design Science Research (Vaishnavi & Kuechler 2014). This was preceded by a systematic literature review, in which an extensive study was conducted on the existing threat-intelligence exchange platforms, including *de facto* and *de jure* threat-exchange standards. From the literature, it was determined that a number of threat-intelligence sharing platforms exist; however, most of these platforms are isolated and do not necessarily adopt any sharing model or use semantic knowledge to ensure that actionable information is shared.

In addressing the main research problem raised in the introduction, the authors followed a conceptual modelling and practical approach to realize a Proof of Concept (PoC) for the proposed semantic-enabled sharing model. The PoC cyber-threat intelligence platform was implemented by using a series of integrated components, including an existing platform (namely, CRITS) as a foundation. In addition, Twitter, a popular social media platform, was selected as one of the data sources. Unlike the other data sources, it is discussed in this article mainly because it is capable of generating Big Data on a daily basis. As a matter of fact, to date, there are over 400 million tweets recorded per day (Tsukayama 2013), and this fact makes it a relevant case as it is highly improbable that one person or organisation can go through all these tweets or even share them with relevant stakeholders using traditional approaches. The following section discusses the technical platform prototyped for evaluating how sharing could occur using a secured web-based portal.

Cyber-threat Intelligence Platform

To combat the impact of cyber-crime and cyberattacks, organisations need to share the known threats with other relevant and trusted organisations as quickly as possible. Enormous amounts of data exist from various sources, such as Twitter. This section explores how the Big Data from a social network such as Twitter could be used to achieve the objective of sharing semantic-enabled, threat-intelligence information. Data can be pulled from Twitter, then filtered and cleaned as it arrives on the system by using API designed by the researchers. It can then be semantically filtered using stakeholder profiles and text-analysis APIs, such as TextRazor (Textrazor 2016).

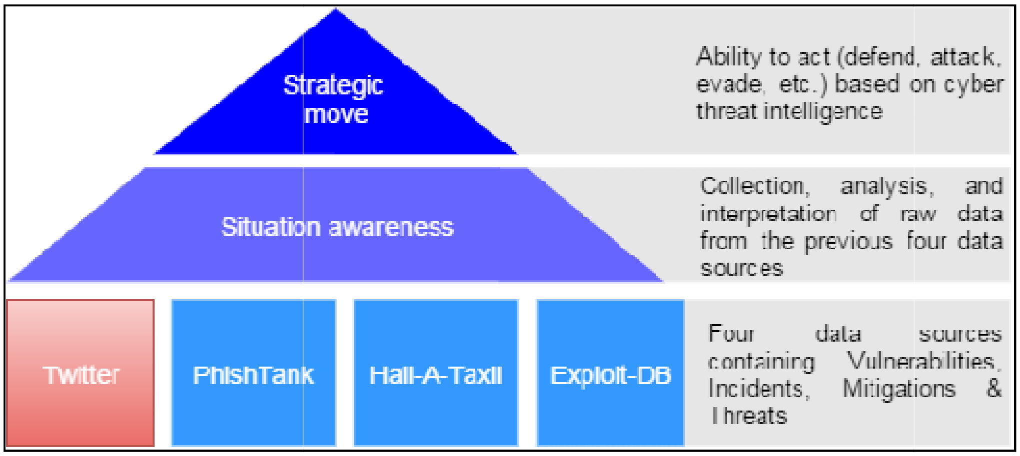

Figure 1: Platform high level architecture

At present, the in-house developed API has four data sources which contain vulnerabilities, incidents, mitigations, and threats. (See **Figure 1**, above.) The feeds from the four data sources are collected together into the database of the API where they are analysed, classified, and interpreted. The cyber-threat intelligence platform then polls from the API feeds using the TAXII poll service in order to generate cyber-threat intelligence information that can be actionable for attack on, defence against, or evasion of a cyber threat.

Figure 2, below, shows a raw Twitter feed, tweeted by the Information Security Hotspot about the SAP software download application that exposes cybersecurity vulnerability. This feed is pulled and converted into STIX format using an API developed for the platform. It should be noted that the Twitter Search API puts restrictions on the number of tweets that can be streamed by external applications; however, from the authors' experiments conducted over a few days, over 300,000 tweets were acquired. For demonstration purposes, Python was used to implement the streaming in-house API. The input to the API is a set of keywords that would assist in sourcing the relevant tweets.

Figure 2: Raw Twitter feed

Once all tweets are cleaned and tagged with the semantic data for the different stakeholders or keywords that a particular organisation is interested in, the tweet can then be pushed to the transport service in a STIX format as illustrated in **Figure 3**, below, from which it can be pulled by any other exchange platform that utilizes the TAXII service. This makes the authors' approach platform-independent and loosely coupled.

```xml
<stix:STIX_Package
        xmlns:URIObj="http://cybox.mitre.org/objects#URIObject-2"
        xmlns:cybox="http://cybox.mitre.org/cybox-2"
        xmlns:cyboxCommon="http://cybox.mitre.org/common-2"
        xmlns:cyboxVocabs="http://cybox.mitre.org/default_vocabularies-2"
        xmlns:example="http://example.com"
        xmlns:indicator="http://stix.mitre.org/Indicator-2"
        xmlns:stix="http://stix.mitre.org/stix-1"
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                            </cybox:Properties>
                        </cybox:Object>
```


Figure 3: Tweet converted into STIX format

Once the above mentioned Twitter feed is STIXified by the in-house API, it can be given a security classification using the Traffic Light Protocol (TLP). The TLP classification is based on the possible impact the security threat would cause. This impact is measured on the estimated severity and length of the attack. **Table 2**, below, shows the threat-level classification of the Twitter feeds. Once the feeds are classified, they can then be pushed to the YETI server. The YETI server then provides three services which are Pushing, Polling, and Discovery. These three services are then consumed by the exchange platform. **Table 2**, below, also shows which cyber-threat intelligence information a public or private user has access to, based on the TLP of the cyber-threat feed. Private stakeholders can view all TLP feeds irrespective of the tag colour, whereas public stakeholders can only view TLP feeds that are tagged with a green colour.

TLP Colour	Threat Level	Description	Public Stakeholder	Private Stakeholder
RED	CRITICAL	Cyber-threat information that cannot be shared outside the organisation		✓
AMBER	HIGH	Cyber-threat information that can be shared outside the organisation		✓
GREEN	MEDIUM	Cyber-threat information that can be shared with anyone	✓	✓

Table 2: Classification of tweets

Shared cyber-threat intelligence can either be viewed in a public or private mode. The public stakeholder is able to see a list of cyber-threat information that is non-classified. This means that the information can be shared with anyone and has limited impact. The private stakeholder is able to see a table list of cyber-threat information that is classified and is only sharable within a group of affected stakeholders. In order to determine if the user can view public or private information, the platform queries the Lightweight Directory Access Protocol (LDAP) server for the type of TLP that the user is allowed to view and also the sharing rights the user has. The Twitter feeds are already classified when they are stored in the platform's local database.

Once the user has successfully logged onto the platform, he or she is immediately presented with a summary dashboard of all types of cyber-threat intelligence information; see **Figure 4**, below. From the main dashboard, the user can see the overview of each category: backdoor, malicious domain, malicious email, malicious indicators, malicious IP, and malicious samples. Each item has its own sub-dashboard with links to new items. The platform is not discussed in detail here due to space limitations.

Figure 4: Platform main dashboard

Conclusion and Further Research

The threats to cybersecurity are on the rise from different sources and for different reasons. This article discusses the need for a collaborative tool that can be used to analyse Big Data related to cybersecurity using rights management to separate publicly and privately accessible intelligence. Herein, intelligence is defined as analysed information that enables actionable reactions by stakeholders to events—in some cases, even before these events occur. For the conceptual model, the authors have discussed several options for the exchange platforms and exchange standards. By putting together the different exchange platforms and exchange standards, a conceptual model was selected and implemented using the experimental and practical research approach. The data sources fed into the conceptual model were raw Twitter feeds, which were STIXified and pulled into CRITS using a TAXII server as the Transport Service. The analysis of this data is displayed on the CRITS dashboard. Further research might include the integration of a mathematical model to measure the value and impact of shared cybersecurity threat intelligence over a period of time.

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