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Localised Internet Scanning Infrastructure

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Declaration

I hereby declare that this project is entirely my own work and that it has not been submitted as an exercise for a degree at this or any other university.

Signed: _____ Date: _____

Abstract

Internet scanning is used for a variety of purposes, some good and some bad. Researchers and commercial entities use internet scanning to find new vulnerabilities, monitor the roll out of mitigations, uncover unadvertised services such as Tor bridges and perform high-speed vulnerability scanning. Attackers use it to find new vulnerabilities and targets with known vulnerabilities.

Internet-wide scanning is a well-explored topic but more localised scanning could produce more actionable results. This project implements a data store and data visualisation tool for such scans. It explains how Elasticsearch was configured to store scan results and describes a CLI tool developed to simplify the process of working with Elasticsearch. It explains how Kibana was used to visualise the data in Elasticsearch and provides some high-level analysis of the data from three scans. Finally, it highlights the strengths and limitations of using the Elastic Stack as part of a localised Internet scanning infrastructure.

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I would like to thank my supervisor Dr. Stephen Farrell for his support and guidance throughout this project.

I would also like to thank my family and friends who have supported me throughout the project and over the last four years.

Acronyms

AS	Autonomous System
AWS	Amazon Web Services
CLI	Command Line Interface
CRUD	Create, Read, Update, Delete
ECDHE	Elliptic-Curve Diffie–Hellman Ephemeral
IANA	Internet Assigned Numbers Authority
IMAP	Internet Message Access Protocol
IP	Internet Protocol
MAC	Message Authentication Code
POP3	Post Office Protocol v3
SMTP	Simple Mail Transfer Protocol
SSH	Secure Shell
TCP	Transmission Control Protocol
TLS	Transport Layer Security

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1 Introduction

1.1 Goal

The goal of this project is to implement a data store and data visualisation tool for a localised Internet scanning infrastructure which supports Ireland-sized Internet scans. It follows on from work completed previously on surveying cryptographic public key re-use, outlined in Section 2.3.

The project aims to achieve the following goals:

- Implement a data store.
- Provide an easy way to ingest scan data.
- Allow easy data analysis and visualisation.
- Use open-source software.
- Be able to run on a machine with limited resources but also be able to scale up.
- Outline steps to deploy to a production environment.

1.2 Motivation

While large-scale, Internet-wide scanning is a well-explored topic, more local scans could produce more actionable results. This project focuses on Ireland-wide scans, but it could be used for other similarly sized scans. The hope is that by using local knowledge and building relationships with key stakeholders (e.g. network operators, hosting providers, etc.), identified issues can be examined more closely and mitigations can be devised and implemented more effectively.

1.3 Report Outline

This report outlines how the Elastic Stack [2] is used to achieve the goals outlined previously. Elasticsearch is used for data storage and Kibana for data visualisation and analysis. The report aims to explain the process of installing and configuring the Elastic Stack, inserting the raw scan results (stored in JSON format) into Elasticsearch and visualising the results in Kibana. It outlines a command line tool developed to simplify this process. Finally, it evaluates the success of the project with respect to the above goals and outlines possible future work.

Chapter 2 outlines the background of the project and related work. It explains what Internet scanning is, some of the reasons for it and some of the technologies used.

Chapter 3 explains the implementation of Elasticsearch as a data store and some of the challenges associated with it.

Chapter 4 describes the use of Kibana as a data visualisation tool and looks at some high-level visualisations and the insights provided by them.

Chapter 5 attempts to determine the success of the project by comparing implementations of the same experiment with and without the infrastructure implemented in this project both in terms of code (quantity and readability) and execution time. It also highlights some of the advantages and disadvantages of the new solution.

Chapter 6 provides some final remarks on the project.

Chapter 7 highlights some work that could be done following on from this project.

2 Background & Related Work

2.1 Internet Scanning

Internet scanning is the process of conducting network scans on an Internet-wide scale. Network scanning is the process of discovering hosts on a network and finding out information about them. Once the hosts on a network have been detected, port scanning can be used to identify ports open on them. Open ports show the services listening on the host, indicating the purpose of the host. For example, a host listening on port 443 is likely a web server using HTTPS. This can be used to get further details about the host by sending a HTTP request using an application-layer scanner.

[3] groups scans into four broad categories:

- **Vertical Scan:** a scan by a single host of multiple ports on another host.
- **Horizontal Scan:** a scan by a single host of a single port on multiple other hosts.
- **Coordinated/Distributed Scan:** horizontal scans by multiple hosts on other hosts in a /24 subnet within a one hour window.
- **Stealth Scan:** horizontal or vertical scan with low frequency with the intention of avoiding detection.

As with port and network scanning, Internet scanning can be used for both good and bad. It is used by system administrators, researchers and commercial entities find new vulnerabilities, monitor the roll out of mitigations, uncovering unadvertised services such as Tor bridges and high-speed vulnerability scanning. It is also used by attackers for finding new vulnerabilities and finding targets with known vulnerabilities.

2.1.1 ZMap & ZGrab

ZMap is a fast, horizontal network scanner designed for Internet scanning. It uses Syn scans for port scanning and can scan the entire IPv4 address space (4,294,967,296 addresses) in

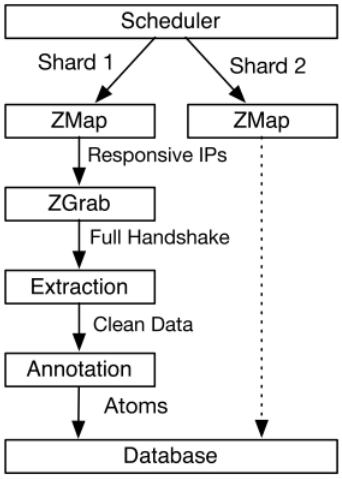

Figure 2.1: Censys.io scanning and annotation process [1]

under 45 minutes with a 10gigE connection [4].

ZGrab is an application layer scanner designed to work with ZMap. It is a banner grabber implemented in Go which can be used to get banner information for protocols such as SSH, SMTP, POP3, IMAP and HTTPS [5]. It logs all information about each request in JSON format. More details about the data logged are given in Section 2.4. It is this JSON data that this project aims to store and analyse.

2.1.2 Censys.io

Censys is a search engine for Internet-wide scans, developed by the team behind ZMap and ZGrab [1] It uses ZMap and ZGrab to continually scan the Internet and get banner information, processes the data and stores it for searching. Since the original paper was published, Censys has begun selling its services for profit. As a result, its software is no longer fully open source and the architecture may have changed. This section describes the Censys architecture as outlined in the original paper.

ZMap is used for host discovery. The output of this seeds ZGrab, the application scanner, which produces structured JSON data containing details of the raw handshake. Another tool, ZTag, is then used to transform this data to a format which is easier to work with and add annotations with additional metadata such as device model. This metadata is not available directly from the scan results but can be derived using logic (e.g. regular expressions on protocol headers) [1]. This scan and annotation process is illustrated in Figure 2.1.

The initial version of Censys, as described in [1], used ZDb for data storage. ZDb was developed as a wrapper for RocksDB with optimisations to avoid disk access when there are no changes to data. MongoDB and Apache Cassandra NoSQL databases were initially

tested, but were found to be too slow to keep up with the fast ZMap and ZGrab scans. The GitHub repository for ZDb [6] has since been marked as deprecated and archived. It is not clear what data store Censys now uses. Google Cloud Datastore is used to store historical data, allowing users to view a history for each host.

Censys provides multiple interfaces for interacting with the data. A web front-end allows users to perform full-text search and structured queries of the data. This is powered by Elasticsearch, whose indexes are updated in real time by the database. A REST API allows programmatic access to the data and supports the same functionality as the web front-end. Data is returned in JSON format. When searching using the front-end or API, the search is performed against the latest snapshot. Google BigQuery allows authenticated researchers to perform more complex SQL queries over the full set of data, including historical data. The system architecture diagram in Figure 2.2 shows the relationship between these interfaces and the data flow.

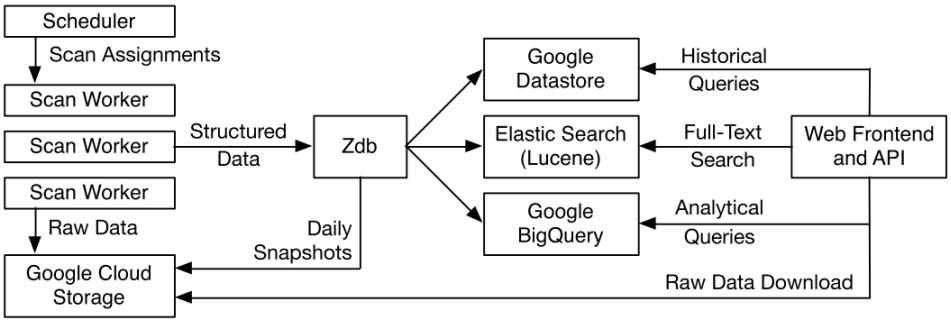

Figure 2.2: Censys.io system architecture diagram [1]

2.2 Port Scanning

Port scanning involves sending client requests to ports on a host to find open ports. If a port is open, a response will be received from the host. While port scanning alone provides limited details about a host, when combined with other tools such as banner grabbers it can become very useful.

Port scanning is conducted for different purposes, some good and some bad. System administrators use port scanning for testing security policies and mapping out networks. Attackers, on the other hand, use it to find vulnerabilities and potential targets.

There are different types of ports scans [7], some of the most common being:

- **Syn Scan:** The port scanner generates and sends a TCP syn packet. If the port is open, the host will respond with a syn-ack packet. If it is closed but unfiltered, the host will respond with a reset. If no response is received, the port is likely blocked by a

firewall. As the TCP handshake is never completed, there is usually no log of the scan recorded on the host.

- **TCP Scan:** The port scanner initiates and completes the full TCP handshake. If the port is open, the handshake will complete successfully. If it does not, the port is likely closed or blocked by a firewall.

2.3 Project Background

This project builds on previous work completed on surveying cryptographic public key re-use which found that key re-use is widespread [8]. That work involved the development of a large number of bash and python scripts to get sets of IP addresses to scan, perform the scans and to analyse the results. As well as data from fresh scans, results from Censys [1] were also used to give a more comprehensive set for analysis.

IP Addresses are selected from either a previous scan or from a new set generated using a geo-location database. When using the latter, the open source MaxMind geo-location database [9] is used to get a set of addresses in a specified region. ZMap is then used to find the subset of these addresses which listen on port 25 (mail servers) to be used for further scanning. Mail servers are used as it is unlikely they are operated by or for individuals, avoiding the associated ethical issues of scanning individual people.

ZGrab is then used to connect to these addresses on a range of ports and to record the details, as outlined in section 2.4. The result of scanning an address is a JSON object which contains details about the host and each port. This object is appended to a results file. This step also verifies that each address is correctly geo-located before performing the scan. This step can take hours to days to complete, depending on the number of addresses and infrastructure used.

The analysis in this work focuses on detecting key re-use using SHA256 public key fingerprints. It uses python scripts to iterate over the scan result file, producing intermediate result files to find clusters of key re-use. JSON files and graphs are generated for each cluster. This process is relatively slow and memory intensive.

The goal of this project, as outlined in Section 1.1, is to implement a data store and data visualisation solution for use with the work described above. The hope is that this will improve efficiency and allow more general data analysis be performed more easily.

2.4 Data Overview

The data for this project is the output of ZGrab scans. As in [8], only IPv4 addresses are used for scanning and all servers scanned listen on port 25. Mail servers are intended to be public, so this avoids scanning personal servers which may give rise to ethical concerns. The output of each scan is a single file. Each line in the file is a JSON object which contains details about one server scanned. Table 2.1 shows the ports and associated protocols scanned. For each port, details are recorded about the TLS handshake and protocol-specific details. For example, when scanning port 443 details about the HTTP request and response are saved including the body, headers and response codes. For all ports, full TLS details including client and server hellos, key exchange parameters and server certificates are saved. The data used in this project came from scans which used TLS version 1.2 and below.

Before data is inserted in Elasticsearch, some additional information is added including geo-location information and scan date. Note: *scan* and *run* are used interchangeably when talking about specific scans, i.e. 2018 scan and 2018 run are the same thing.

Appendix A1 shows the outline of the result of scanning a single server extracted from the 2018 scan. The server is listening on all ports scanned.

Port	Protocol
22	SSH
25	SMTP
110	POP3
143	IMAP
443	HTTPS
587	SMTP Submit
993	IMAPS

Table 2.1: Ports and protocols used in scans

Data from three scans, shown in Table 2.2, are used for this project. The 2018 and 2019 scans were scans runs locally as outlined in Section 2.3. The 2017 scan data was extracted from Censys.io. As Censys performs additional processing of the data, the structure of the 2017 data is different than 2018 and 2019. While much of the same information is available in both types, the field names are different. This leads to issues when searching and aggregating data in Elasticsearch and when visualising data in Kibana. Throughout this report, the field names used are those used in the fresh scans. If the field name is the same in the Censys data, results from all three scans are included and if not, only results from the fresh scans are shown.

A subset of data from each of the three scans was also used for development and testing.

The tool described in Section 3.3.2 was used to extract the subset using a list of 100 aviation companies in Ireland.

Scan Date	Source	Number of Hosts
30 November 2017	Censys.io	23,616
16 March 2018	Fresh ZGrab	24,774
15 January 2019	Fresh ZGrab	27,044

Table 2.2: Scan data used for development

2.5 Elastic Stack

Elasticsearch is a search engine and NoSQL database which supports schema-less JSON documents, based on Apache Lucene. It is highly scalable and can handle petabytes of data across hundreds of nodes [10]. It uses an open-core model, where the core functionality is open-source and additional premium features are available through subscriptions. This project utilises only the open-source features.

Elasticsearch uses a REST API for almost all interactions: managing clusters, nodes and indices and performing data CRUD and search operations.

Below is a short explanation of some basic concepts in Elasticsearch:

- **Document:** a document is the basic entity that can be indexed in Elasticsearch. It is a JSON object that contains fields which describe a single entity. In this project, a document contains the results of a single scan of a single server. Every document is associated with one index. Every document has a unique ID which is automatically generated by Elasticsearch when it is first created.
- **Index:** an index is a collection of similar documents. Every index has a unique name that is used when managing the index and when performing operations on the documents within in. For this project, each scan and scan subset has its own index. For production, it is recommended that multiple similar scans use a single index, as explained at the end of Section 3.4.1
- **Shard:** documents in an index are stored in shards. An index has one or more primary shards and every document is stored in a single primary shard. Shards allow indices to be split across multiple discs and nodes for horizontal scaling. Each shard can be searched independently, thus having multiple shards improves search performance. An index has zero or more replica shards. Replica shards are used to provide redundancy, allowing shards to be replicated across nodes. Elasticsearch manages replication and

automatically switches to replica shards (if available) when the node of the primary shard fails.

- **Node:** a node is a server that runs Elasticsearch and is part of a cluster. Every node has a unique name to identify it.
- **Cluster:** a cluster is a collection of one or more nodes. Every cluster has a unique name to identify it. Nodes join clusters using the cluster name. Clusters allow horizontal scaling for performance and redundancy.

Kibana is a data analytics and visualisation tool built by the Elastic team that integrates with Elasticsearch. Like Elasticsearch, it uses an open-core model, with only open-source features used in this project. As well as allowing data exploration and visualisation of data stored in Elasticsearch, it allows monitoring and basic management of Elasticsearch indices and clusters.

Below is an explanation of some key terms used when discussing Kibana:

- **Visualisation:** a visualisation is a graphical way to display data in Kibana. There are several types of visualisations, including bar charts, line charts, maps, tag clouds and tables. A visualisation can display data from an entire index pattern or from a user-defined search query.
- **Dashboard:** a dashboard is a screen which displays multiple visualisations. Filters can be used to narrow down the data and are applied to all visualisations on the dashboard. Visualisations on a dashboard are interactive and allow filters to be applied by clicking on the visualisation. For example, clicking on a region on a map would filter the data used by all visualisations on the dashboard to documents which match that region.
- **Index Pattern:** an index pattern defines the Elasticsearch indices to be used. If the index pattern name matches the Elasticsearch index name, only that index will be used. Wildcards can be used to match multiple indices meaning data stored in separate indices in Elasticsearch can be used in the same visualisations in Kibana.
- **Scripted Field:** a scripted field is a field which is computed at query-time using the values in other fields. As it is not indexed, it is quite resource intensive and recommended only for simple expressions and non-real time queries. Scripts can be written in Painless, Elasticsearch's custom scripting language (recommended), or as Lucene expressions. Scripted fields are similar to computed/generated columns in SQL.

2.5.1 Lucene

2.6 Transmission Control Protocol

Transmission Control Protocol (TCP) is a connection-oriented, reliable transport layer protocol designed to be used between two hosts which are on the same network or are on interconnected networks [11, 12]. It provides error detection, re-transmission, sequencing and flow control. TCP has three main phases of operation: connection establishment (TCP Handshake), data communication and connection closing [12].

2.7 Application Layer Internet Protocols

2.7.1 SSH

The Secure Shell (SSH) protocol is a network protocol which allows secure remote access over insecure networks [13]. It provides an encrypted tunnel between the client and the server, as well as client and server authentication. It runs over TCP and has been assigned port 22 by IANA [14].

2.7.2 SMTP

Simple Mail Transfer Protocol (SMTP) is an electronic mail protocol designed to transfer mail reliably and efficiently. SMTP can run over any transport service which provides a reliable ordered data stream, most commonly TCP [15]. IANA has assigned ports 25 and 587 to SMTP [14]. Port 25 is most commonly used between mail servers, while port 587 is reserved for email message submission [16].

2.7.3 POP3

Post Office Protocol version 3 (POP3) is an electronic mail retrieval protocol used by email clients to retrieve mail that a mail server is holding for it[17]. Once an email has been retrieved by the client, it is deleted from the server. It runs over TCP and has been assigned port 110 by IANA [14].

2.7.4 IMAP & IMAPS

Internet Message Access Protocol (IMAP) is an electron mail protocol which allows a client to read manipulate emails on a server [18]. Unlike POP3, emails are not deleted on the server after they are read by a client. This allows synchronisation of a single mailbox across multiple clients, among other advantages. It can run on any reliable data stream, usually TCP. It has been assigned port 143 by IANA [14].

IMAPS is a secure version of IMAP which uses TLS. While IMAPS can be used on port 143 using the STARTTLS mechanism, it is recommended that port 993 is instead used for implicit TLS [14, 19].

2.7.5 HTTPS

Hypertext Transfer Protocol Secure (HTTPS) is a secure version of HTTP which uses TLS. It can be run over any transport service which provides a reliable connection-oriented data stream, usually TCP [20]. It has been assigned port 443 by IANA [14].

2.8 Transport Layer Security

Transport Layer Security (TLS) is a cryptographic protocol which provides secure communication over a computer network. Symmetric cryptography is used to encrypt data between two applications using keys unique to that connection, ensuring a private connection. The keys are based on a shared secret, negotiated during the TLS Handshake. Message authentication codes, computed using secure hash functions, are used to ensure a reliable connection [21]. The TLS Handshake protocol is used to set up the secure connection.

2.8.1 TLS Handshake

The TLS Handshake is initiated by the client once the TCP connection has been established.

1. **Client Hello:** the client sends a hello message to the server. In it, the client states the version of TLS and the cipher suites it supports, as well as a client nonce (random number).
2. **Server Hello:** the server chooses the highest mutually supported TLS version to use. It chooses a cipher suite from the list of those supported by the client and generates a

server nonce (random number). It then sends these three things along with its TLS certificate.

3. **Server Verification:** the client attempts to verify the server's TLS certificate with the issuing Certificate Authority to ensure the server is who it says it is.
4. **Pre-Master Secret:** the client generates another random number called the Pre-Master Secret (PMS). It gets the server's public key from the certificate, encrypts the PMS using the key and sends the encrypted PMS to the server.
5. **Master Secret:** using the client nonce, server nonce and PMS, the client and server independently compute the master secret using the same key derivation function, as specified by the TLS standard [21]. They should both get the same result. The master secret is then split up to give a client MAC key, a server MAC key, a client encryption key and a server encryption key.
6. **Client Ready:** the client sends a message, encrypted using the derived client encryption key, to the server to indicate that it is ready to use encrypted messages from now on.
7. **Server Ready:** the server decrypts and verifies the message received from the client and sends a message to the client indicating that all further messages will be encrypted.

2.8.2 TLS Certificate

2.8.3 Cipher Suite

A cipher suite is a set of algorithms that are used to secure a connection in TLS. A set contains a key exchange algorithm, a symmetric encryption algorithm and a message authentication code (MAC) algorithm. When RSA is used for key exchange, it can also be used to authenticate the server - if the server successfully decrypts the pre-master secret encrypted by the client using the servers public key, it demonstrates that it knows the private key. When Diffie-Hellman is used for key exchange, either fixed parameters can be provided by the server, or it can send temporary parameters using the server key exchange message.

Forward secrecy prevents encrypted communication from being decrypted at a later point, even if the private key becomes compromised [22]. This is achieved using session keys and is an advantage of using Diffie-Hellman for key exchange.

2.8.4 Public Key Fingerprint

A public key fingerprint is a cryptographic hash of a public key. As it is shorter than the key it represents, it can be used in place of the key to simplify some tasks. This project focuses on using the SHA256 hash of public keys. [8] explains the input for the hash, "For TLS services, the hash input is the encoded SubjectPublicKeyInfo field of the X.509 certificate presented by the server. For SSH, the SSH key hash as produced by ssh-keygen is used".

2.8.5 SHA256

A hash function takes an input x and computes a string of fixed size $H(x)$. A cryptographic hash function is one for which it is computationally infeasible to find two messages x and y which give $H(x) = H(y)$ [23] and given $H(x)$ it should be infeasible to find x. In other words, it should be infeasible to (1) find two messages which produce the same hash and (2) find a message that corresponds to a given hash [24]. SHA256 is a Secure Hash Algorithm whose output is 256 bits in length.

2.9 Autonomous System

An Autonomous System (AS) is "a connected group of one or more IP prefixes run by one or more network operators which has a SINGLE and CLEARLY DEFINED routing policy" [25]. ASes are used by internet service providers.

3 Data Store

This chapter outlines the configuration of Elasticsearch for this project, explains some of the features used and outlines challenges encountered. It also describes a command line tool developed as part of this project to simplify the process of installing and managing Elasticsearch and working with the data.

3.1 Data Types and Mappings

Elasticsearch uses mappings to define how to store and index documents and fields. A mapping can be used to define the type and the format of a field where applicable (e.g. a date). Dynamic mapping allows documents to be inserted without explicitly defining mappings for every field. This was essential for this project for a number of reasons:

- **Number of Fields:** there were over 5,000 unique fields in the data from the three scans used for this project. Explicitly defining mappings for each of these would be difficult and tedious.
- **Extensibility:** future work may extend scanning to additional protocols or add additional data processing and transformations. Dynamic mapping allows these changes to be made without the need to make any changes to Elasticsearch.

There were cases, however, where explicit mappings were needed as the correct types or formats were not detected automatically.

- **IP:** Elasticsearch has an IP datatype which supports IPv4 and IPv6 addresses. It allows searching IP addresses within ranges and using CIDR notation. When using dynamic mapping, the IP field was detected to be of type string.
- **Geo-Point:** the geo-point data type stores latitude and longitude pairs which can be used to plot points on a map, as shown in Section 4.3. Without an explicit mapping, the latitude and longitude fields were represented as independent number fields.
- **Date:** explicitly defining the format for the date fields ensures the date is returned in

the expected format in search results.

3.2 Index Templates

Elasticsearch allows index configuration settings to be set when creating the index, using the *_settings* API endpoint or in an index template. An index template is a JSON file which contains settings and mappings to be used when creating matching templates. Table 3.1 shows the settings used in the default index template in this project. The template also contains the mappings explained in Section 3.1.

The *index_patterns* field is used to set indices the template should be applied to. The template will be applied to an index if the index name matches the value pattern. The field takes an array which can be used to give multiple index names to which the template will be applied. Wildcards can be used in the patterns.

Multiple templates can match an index name.The *order* field is used to determine the order in which templates are applied. Templates are applied in order from lowest to highest. Higher order templates take precedence over lower order ones. This allows general settings and mappings to be set for all indices and more specific ones to be set for certain indices.

The *index.mapping.total_fields.limit* field is used to define the total number of unique fields an index can contain. Information about each field is stored in memory, so having too many fields can cause memory errors. Testing for this project showed an average of 3,000 fields per index when separate indices were used for each scan. If data from different sources (e.g. Censys.io and fresh ZGrab) were stored in the same index, this field would need to be increased. There are 5,610 unique fields when the data from all three scans are combined. The number of unique fields should not vary significantly between similar scans. If the number was significantly different, it may indicate an error, e.g. encoding issues or other problems with the raw JSON. If the structure of the JSON changed significantly, e.g. as a result of new data transformations, the data should be added to a new index.

The *number_of_shards* field is used to set the number of primary shards for an index. This can only be set when an index is created; it can't be changed later using the *_settings* API.

The *number_of_replicas* field is used to set the number of replica shards for an index. Having a replica shard on the same node is of little benefit. Replica shards on separate nodes provide a backup in the case of failure of a node. The maximum number of replica shards should be $(\#nodes - 1)$. In this case, one node will host the primary shard and every other node will host a replica of it.

The *version* field is optional and is not used by Elasticsearch internally. It is intended to simplify template management by administrators or other systems. The *_template* API endpoint can be used to get version of a template used when creating an index.

Changes to index templates are only applied to new indices created after the template is update and not to existing templates.

Field Name	Value	Explanation
index_patterns	["*"]	This template will be applied to all new indices.
order	1	Using order 1 overrides Elasticsearch default templates (order 0).
index.mapping.total_fields.limit	5000	Allows true fields to be set but prevents mapping explosion in the case of an error.
number_of_shards	1	Section 3.4.1 explains why 1 primary shard is used for this project.
number_of_replicas	0	Single node cluster with no replication.
version	1	

Table 3.1: Settings in default Elasticsearch index template used for this project.

3.3 CLI Tool

3.3.1 Installing Elasticsearch & Kibana

```
Usage: esman installdeps [OPTIONS]

  Install Elasticsearch and Kibana, enable auto-start and create
  Elasticsearch templates

Options:
  -h, --help  Show this message and exit.
```

Figure 3.1: Command to install Elasticsearch and Kibana

Figure 3.1 shows how to install the Elastic Stack components used for this project. It installs Java, Elasticsearch and Kibana, enables the services to run them automatically on startup and creates the default Elasticsearch templates.

3.3.2 Extracting Subset

```
Usage: esman extractsubset [OPTIONS]

  Read a CSV file, one (default second) column of which is a URL, then
  extract matching records from a JSON file

Options:
  -c, --csvinfile TEXT    CSV file containing list of domains  [required]
  -j, --jsoninfile TEXT   JSON file containing list of scan records
                          [required]
  -o, --output_file TEXT  JSON file in which to put records (one per line)
                          [required]
  --col INTEGER           Column from input file that has the URL (default =
                          1)
  --tryip                 If set, searches json_infile for IP if no records
                          match domain
  --debug                 If set, turns on verbose logging
  -h, --help              Show this message and exit.
```

Figure 3.2: Command to extract data subset

Figure 3.2 shows how to extract a subset of data from a JSON file. This is intended to be used with the *AddDNSDetail* script developed previously as part of the overall project [26], but it can also be used independently. It takes a CSV file which contains a list of domain names and optionally a list of IPs and a JSON file to search. For each domain in the CSV file the entire JSON input file is searched record by record. If a match for the domain is found in a record, the record is added to the output fie. If no match is found for the domain and the *tryip* flag is set, the input file is again searched, this time using the IP.

This is an imperfect solution, but it is sufficient for this project. As it searches entire records, if one domain is referenced by another, it will match for both domains. For example in the aviation subset used for this project, the server for Ireland West Airport responded on port 443. On the homepage, there are references to the Ryanair and Aer Lingus websites. As a result, the record for Ireland West Airport matched for ryanair.com, aerlingus.com and irelandwestairport.com.

3.3.3 Inserting Data

```
Usage: es insert [OPTIONS]

  Insert JSON Data to Elasticsearch

Options:
  -i, --input TEXT              JSON File to be inserted  [required]
  --index TEXT                  Elasticsearch index to be inserted to
                                [required]
  -rd, --rundate <YYYY-MM-DD>   Run date to be used for Kibana
  -cc, --countrycode TEXT       Two letter country code to be used for Kibana
  -h, --help                    Show this message and exit.
```

Figure 3.3: Command to insert JSON file into Elasticsearch

The raw data for this project is the JSON output from ZGrab, as described in Section 2.4. Each JSON file contains approximately 25,000 records and is 800MB - 1GB in size. With 2GB RAM available and Elasticsearch needing at least 1GB, it is not feasible to load and insert the entire file in one go. To overcome this, a python generator is used with the Elasticsearch python library to load a fixed number of records at a time and insert them into Elasticsearch in bulk. Before sending the data to Elasticsearch, geolocation information is added for each record using code developed in the original work [27]. Each scan file took approximately four hours to insert. A progress bar and the estimated time to completion are displayed to the user. Figure 3.3 shows the command to insert data and the options.

3.3.4 Managing Indices

```
Usage: es viewallindices [OPTIONS]

  View all Elasticsearch indices and their status

Options:
  -h, --help  Show this message and exit.
```

Figure 3.4: Command to view all indices

Figure 3.4 shows the command to view all Elasticsearch indices and information about them including number of primary and replica shards, number of documents and health status. This was used frequently when developing the code to insert the data in bulk and overcoming the problem described in Section 3.4.1. It is much more convenient than using the alternative command shown in Listing 1.

```
\$ curl -X GET "localhost:9200/_cat/indices?v"
```

Listing 1: Curl command to view indices

```
Usage: es deleteindex [OPTIONS]

  Delete an Elasticsearch index. WARNING: Cannot be undone

Options:
  -i, --index TEXT  Name of the index to delete  [required]
  --yes             Confirm the action without prompting.
  -h, --help        Show this message and exit.
```

Figure 3.5: Command to delete index

Figure 3.5 shows the command to delete an Elasticsearch index. As with the previous command to view indices, this was added for convenience to replace the cumbersome alternative shown in Listing 2. It also adds a layer of safety by using a confirmation prompt. This can be skipped using the *–yes* flag to allow use in scripts.

```
\$ curl -X DELETE "localhost:9200/indexname"
```

Listing 2: Curl command to delete an index

3.4 Challenges

3.4.1 Elasticsearch Crash on Bulk Insert

The biggest challenge and one of the most time consuming parts of this project was successfully inserting the raw data into Elasticsearch in bulk. It was initially anticipated that this would be a straightforward task - read the data from the JSON file and insert it into Elasticsearch. The first attempt at doing this used a Python script to read 100 JSON records from the raw data file and send them to Elasticsearch in a bulk insert request.

The output from the python script showed that the data was being read from the file and sent to Elasticsearch. However, checking the number of documents in the Elasticsearch index showed that a very small number of records was being stored by Elasticsearch compared to the number of records sent to it. Initially, the requests were being queued by Elasticsearch and could be seen in Elasticsearch's thread pool. After approximately 200-300 requests, Elasticsearch would close all active HTTP connections and refuse any further incoming insert requests. The python script would log the HTTP connection timeout and

attempt to re-establish a connection. Again viewing the number of documents in the index would show few-to-no additional records had been inserted. The thread pool showed that the requests were being removed from the queue and marked as rejected. At this stage, Elasticsearch would become sluggish and slow to respond to status requests. Eventually, Elasticsearch would crash.

Several attempts were made to overcome the problem. The chunk size (number of records per request) was reduced first to 50 and then to 10, and the max size of the request in bytes was reduced from the default of 100MB to 5MB. Sleep timers were added to the python script to control the rate at which insert requests were sent. After a record was read from the JSON file, the script would wait for one second before continuing. After a request was sent, the script would wait for ten seconds before starting the next read. This meant an insert request was being sent approximately every 60 (10 + 50) or 20 (10 + 10) seconds, depending on the chunk size. As the python script and the Elasticsearch instance were running on the same machine, a check was also added to ensure Elasticsearch was running before a request was sent. If Elasticsearch wasn't running (i.e. had crashed), the Elasticsearch service would be started again and the script would wait for 20 seconds before sending the request. While initial indications appeared to suggest these changes were successful, the process completed after approximately 10 hours with only 18,000 / 24,700 records stored.

Elasticsearch organises documents into indices. Each index consists of one or more shards. A shard is associated with a single Lucene index. A document is stored in one primary shard and zero or more replica shards. As each primary shard is independent of the others, multiple shards can be searched in parallel and the results can be combined. Replica shards can be used to provide redundancy by replicating the data across nodes. Figure 3.6 shows an Elasticsearch cluster with two nodes. Each index has three shards, each with one replica.

Data in shards are stored in immutable Lucene segments. The number of segments varies over time as segments are periodically merged into larger segments. Segments are immutable, so the new segment must be created before the old ones can be deleted. This leads to a fluctuation in disk space. Merging is a resource intensive process.

Elasticsearch stores cluster state in memory. This contains information about mappings for every field in every index, state information about every shard and information about where data is physically stored on disk for every segment in each shard [28]. This means overhead is directly proportional to the number of fields, indices and shards. Elasticsearch recommend a maximum of 20 shards per GB heap available and a heap size of 50% of available memory. By default, new indices created in Elasticsearch have five primary shards, each with one replica, giving ten shards per index.

Figure 3.6: Elasticsearch architecture with one cluster, two nodes, two indexes with three shards, each with one replica

This project used a single machine with 2GB of RAM and 6GB of swap memory available. Using the default configuration and following the recommended limits, this would allow a maximum of two indices without Kibana. Kibana uses an index with a single primary shard to store objects, as well as two single-shard indices per day for the current day and previous seven days containing monitoring information about Elasticsearch and Kibana. This results in 17 system indices and shards. Creating a single index with the default configuration alongside the system indices exceeds the recommended limits.

For development and testing, a new index was created for each scan and scan subset. Each of these indices had over 5,400 unique fields. While the fields were different for the 2017 data, they were the same for 2018 and 2019. As they were created as separate indices, however, Elasticsearch treats them as separate fields, effectively storing information about them twice in the cluster state.

To overcome these issues, a number of changes were implemented.

- **Heap Size:** the heap size was set to 1GB, 50% of the RAM available.
- **Index Templates:** index templates were created which allowed the number of primary and replica shards to be defined. As the average number of documents was relatively small (25,000 records per scan), the heap size was limited and search performance was not a priority, the number of primary indices was set to 1. With only a single node cluster for development, the number of replica shards was set to 0.

- **Number of Indices:** frequent changes in mapping types and fields made it more convenient to use separate indices for each data set during development. For production use, however, a different scheme would be required. Depending on the frequency of scans, a single index could be used for a month of daily scans or a year or more of monthly scans of a specific country or region. This would reduce the amount of duplicate field information in cluster state, reducing overhead.

3.5 Elasticsearch Summary

Index Name	Data	Documents	Size (MB)	Shards
records-fresh-ie-20190115	Ireland 2019	27,044	904	1
records-fresh-ie-20180316	Ireland 2018	24,774	811	1
records-fresh-ie-20171130	Ireland 2017	23,616	255	1
av-records-fresh-ie-20190115	Aviation 2019	113	13	1
av-records-fresh-ie-20180316	Aviation 2018	120	13	1
av-records-fresh-ie-20171130	Aviation 2017	80	5	1

Table 3.2: Summary of Elasticsearch indices used for analysis. *Data* refers to the scans results stored in the index (see Section 2.4), *Documents* is the number of documents (servers) in the index and *Shards* is the number of primary shards.

Table 3.2 shows the indices used to store the results of the three scans as well as the aviation data subsets of those scans. The difference in physical size of the data when stored in Elasticsearch versus in a raw text file is negligible; index metadata makes the Elasticsearch data marginally larger.

4 Data Analysis

This chapter explains the set up of Kibana for this project. It demonstrates how Kibana could be used to explore scan data using example visualisations and dashboards based on the full and subset scan data outlined in Section 2.4. It explains a sample Elasticsearch query and describes the process of creating a simple visualisation based on that query.

4.1 Web Server and TLS Certificate

Kibana is a browser-based tool. To allow secure access to it during development, an nginx [29] web server was set up with basic authentication. A self-signed TLS certificate was used to provide a secure connection. The server running Kibana is only accessible from within the Trinity College network (not Internet facing), so a free browser-trusted TLS certificate from Let's Encrypt [30] couldn't be used.

4.2 Elasticsearch Queries

Elasticsearch queries can be performed from the command line using Elasticsearch's REST API or through a console in Kibana. Regardless of the method used to send the request, the query itself can be defined using parameters in the request or in the request body in JSON format. The latter is generally the preferred method as it is more readable and supports more complex queries.

Appendix A2.1 shows a query which gets the breakdown of cipher suites used by servers who share the same SHA256 fingerprint on port 443, grouped by scan date. This was used to answer the question "of the servers listening on p443 who share the same fingerprint, what cipher suites do they use?". If just one server uses a weak cipher suite, it leaves the rest of the servers more vulnerable. This information could be shared with the owner of those vulnerable servers. If the servers are owned/run by two separate entities, those with the strong cipher suite(s) would likely be unaware of the vulnerability and believe that by using a

strong cipher suite, they are safe in that regard.

The *aggs* (or *aggregations*) field is used to define aggregations. Aggregations are simply used to aggregate data based on a search query[10]. Aggregations can be nested as sub-aggregations which take the result of their parent aggregation as their input. The first field in an aggregation (*fingerprint* in this case) is an arbitrary label used to identify it.

The first meaningful field in an aggregation defines its type. The **terms** aggregation is used to group fields based on their value, similar to the `GROUP BY` statement in SQL. Within the terms aggregation, the *field* field defines the field to group by, the *size* field defines the number of buckets to use and *order* defines how the results should be ordered. In this case, the 15 most used SHA256 fingerprints will be returned for the fingerprint aggregation. The result of this is used by the cipher suite aggregation, which gives a breakdown of the cipher suites used by each of the top 15 fingerprints.

```
"terms": {
    "field": "doc.p443.data.http.response.request.tls_handshake
                .server_certificates.certificate.parsed
                .subject_key_info.fingerprint_sha256.keyword",
    "size": 15,
    "order": {
      "_count": "desc"
    }
  }
```

Listing 3: Fingerprint Aggregation

```
"terms": {
    "field": "doc.p443.data.http.response.request.tls_handshake
                .server_hello.cipher_suite.name.keyword",
    "size": 15,
    "order": {
      "_count": "desc"
    }
  }
```

Listing 4: Cipher Suite Aggregation

The **date_histogram** aggregation is used to group fields of type date. Within in the date_histogram aggregation, the *interval* field is used to define the date range for each bucket and the *min_doc_count* field allows only significant buckets to be returned. In this case, an interval of 30 days is used to group the results of the cipher suite aggregation.

```
"date_histogram": {
    "field": "doc.run_date",
    "interval": "30d",
    "min_doc_count": 1
  }
```

Listing 5: Scan Date Aggregation

The *size* field in an Elasticsearch query determines the number of source documents to return. In this case, only the aggregation result is wanted, so size is set 0 so no scan results are returned. The query field is used to filter the data to be aggregated, similar to the SQL `WHERE` clause. In this case, we want to aggregate based on all scan results, so we use the *match_all* query.

```
"size": 0,
"query": {
 "bool": {
   "must": [
     {
       "match_all": {}
     }
   ]
 }
}
```

Listing 6: Elasticsearch Query

Appendix A2.2 shows part of the result of the above query with only one bucket shown for the fingerprint aggregation. The first 14 lines shows metadata about the query itself: the time taken, details about the shards searched and the number of documents included in the results (*hits*). The aggregation result shows that 22 results were found which used a public key with fingerprint *9f00503...7a94*. Of those 22 results, 14 used the cipher suite *TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA*, 4 used the cipher suite *TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256* and 4 the cipher suite *TLS_RSA_WITH_AES_256_CBC_SHA*. The results also further break down the results by scan date.

4.3 Visualisations

4.3.1 Creating Visualisations

The previous section described an Elasticsearch query to get the breakdown of cipher suites used by servers who share the same SHA256 fingerprint, grouped by scan date. This section will describe how to get the same results displayed graphically in Kibana.

Kibana bar charts require two basic things - a metric (aggregation) for the y-axis and a bucket (grouping) for the x-axis. In this case, to show the count of the number servers who have the same SHA256 fingerprint on port 443, the metric for the y-axis is set to 'Count'.

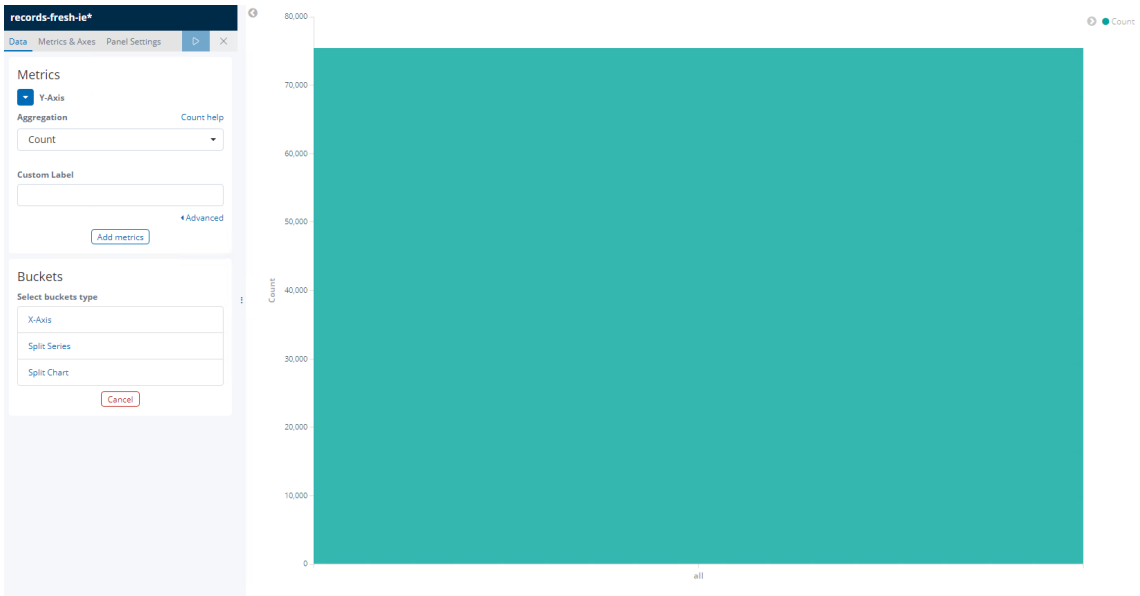

Figure 4.1: Kibana Visualisation - Setting y-axis to count

The goal is to group the servers by SHA256 fingerprint and display the fingerprints along the x-axis in decreasing order by count (i.e. display the most used fingerprint first, followed by the second most used, etc.). To do so, the primary x-axis bucket is set to be the p443 SHA256 fingerprint field and the *order by* field is set to count. Note that, because the data has yet to be further subdivided, the count used for ordering is the total number of records in the data which contain a given key, regardless of run. This means if a server is present in two scans, it will be counted twice for the purpose of ordering. This does not affect the final result.

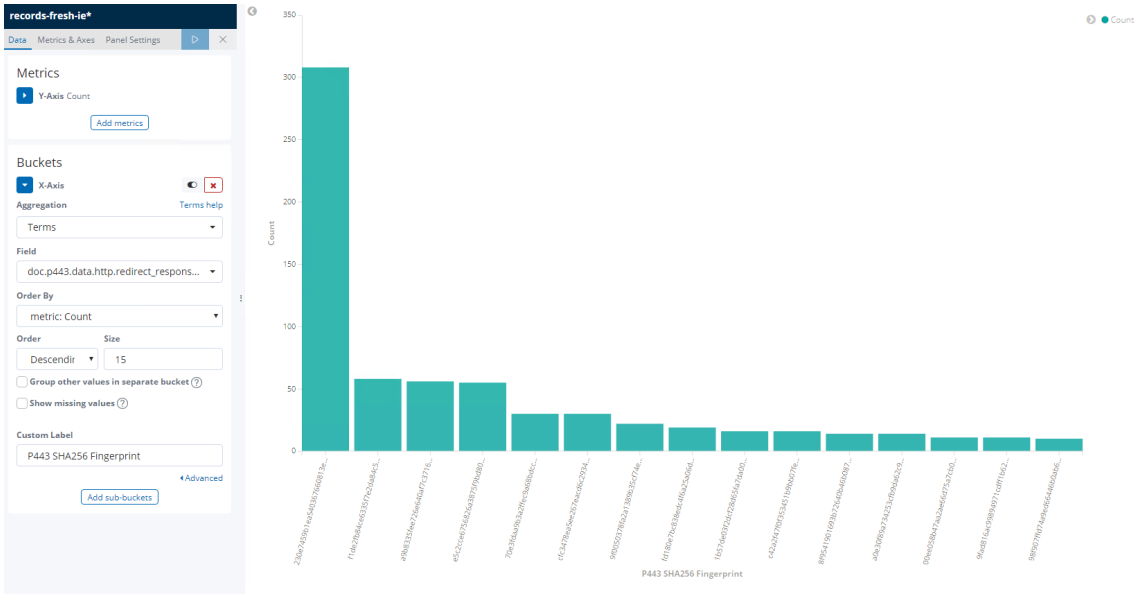

Figure 4.2: Kibana Visualisation - Setting primary x-axis bucket to p443 SHA256 fingerprint

To break down the count by the cipher suite used, a sub-bucket is created using the terms aggregation with the p443 cipher suite field.

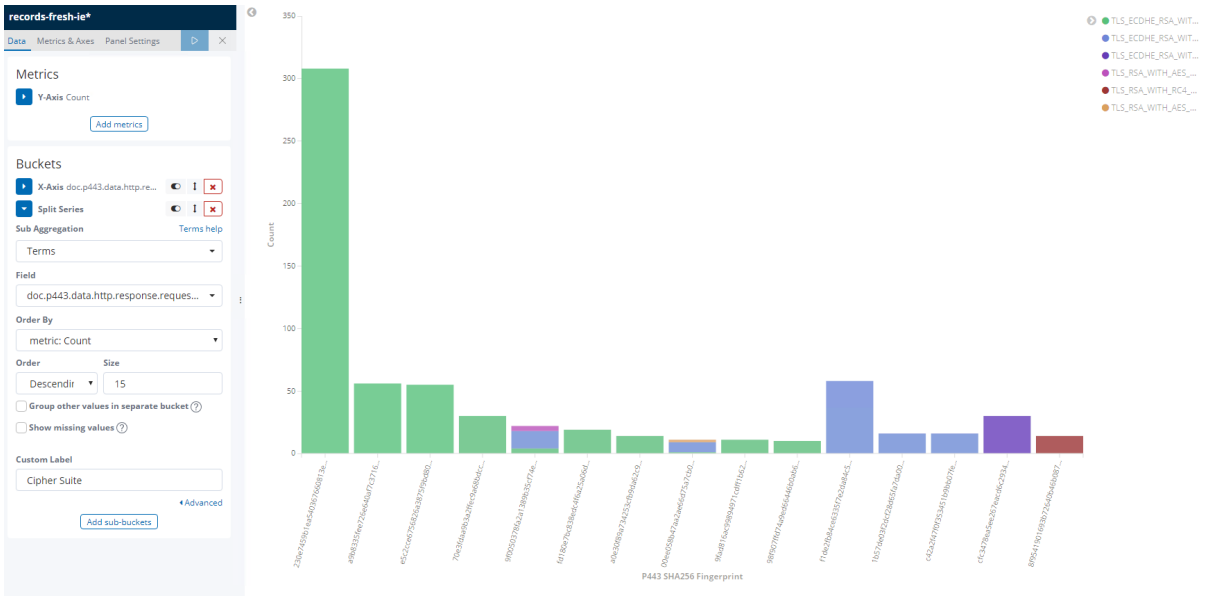

Figure 4.3: Kibana Visualisation - Setting x-axis sub-bucket to cipher suite

Finally, a sub-bucket using the date histogram aggregation is created to split the chart by scan date. This allows the change in usage of each fingerprint and cipher suite over time to be seen by showing each scan as a separate sub-graph.

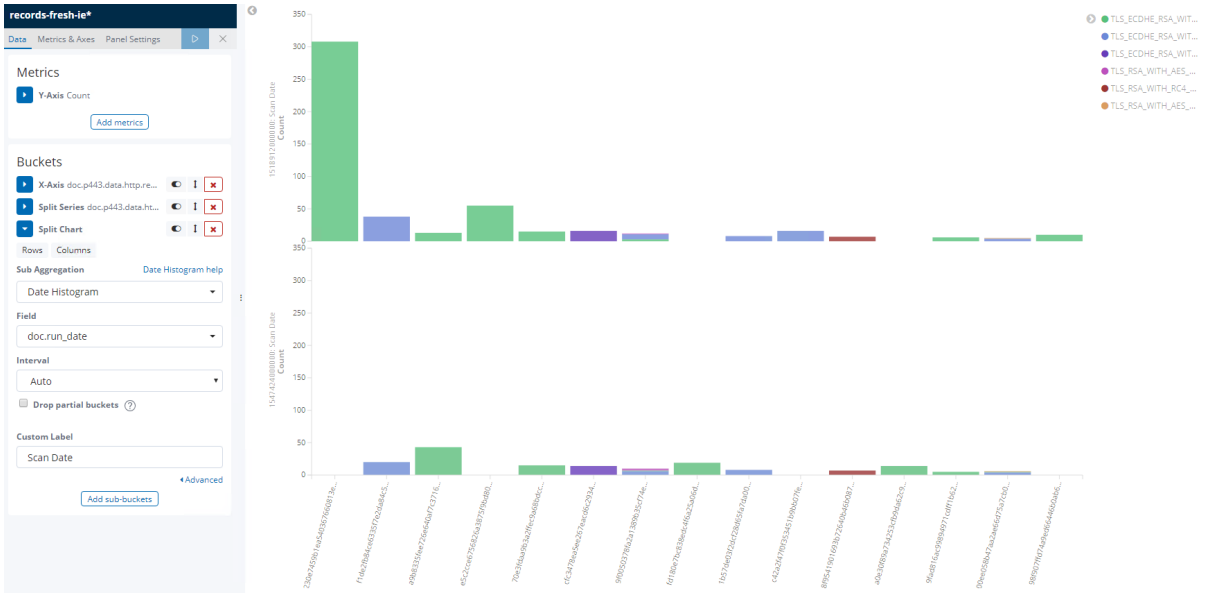

Figure 4.4: Kibana Visualisation - Setting x-axis sub-bucket to scan date

Using Kibana visualisations to analyse the data is much easier and more user friendly than using raw Elasticsearch queries. It allows more exploration as buckets can easily be added, removed and updated and intermediate results can be viewed visually.

4.4 Results & Insights

The two dashboard described in this section use Kibana index patterns with a wildcard to include the three relevant Elasticsearch indices. Most of the results are based only on the 2018 and 2019 results, due to the differences in data structure outlined in Section 2.4. Additional scan results would be needed to provide more conclusive results, but comments are given to illustrate some possible insights the infrastructure this project developed could provide.

4.4.1 Ireland Dashboard

The Ireland Data dashboard shows visualisations using the three full data sets outlined in Section 2.4.

Figure 4.5 shows the number of servers listening on each port for the 2018 and 2019 scans. This graph uses scripted fields, one for each port, which return 1 if there is no error message (i.e. a response was received) and 0 otherwise. Generally, the total number of servers and the number of servers listening on each port is increasing, with the exception of ports 22 and 25. The decrease in servers listening on port 22 is positive from a security perspective. It

does not necessarily mean that SSH use is decreasing, but could be a result of administrators using firewall rules to restrict port 22 access to specific sources, e.g. with specific IP addresses or on local network. While the number of servers listening on port 25 is decreasing, the number listening on port 587 is increasing. This suggests administrators are taking advantage of the separation of mail submission and mail relay provided by [16].

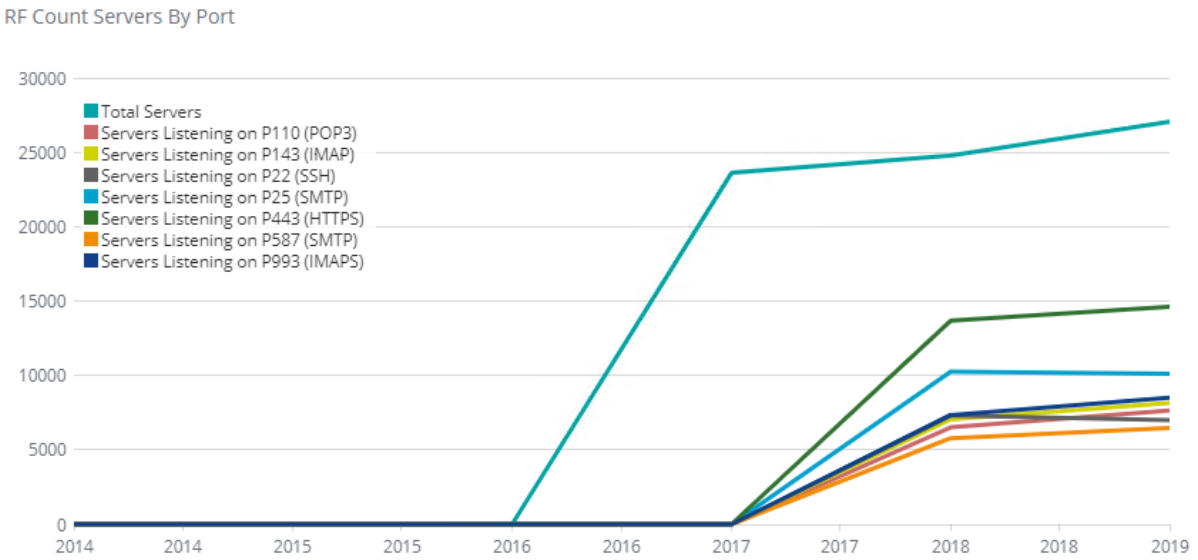

Figure 4.5: Ireland Dashboard: Count of servers by port

Figure 4.6 shows the count of servers using the five most common cipher suites on p443 by scan. There is a 22.22% (+1,827) increase in the number of servers using *TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256* versus a 6.87% (+939) increase in number of servers listening on port 443. This means the increase in *TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256* usage is not only as a result of new servers, but rather servers which used a different cipher suite in the 2018 scan are using it in the 2019 scan. This is positive as it is a strong cipher suite.

There is a decrease (-237) in the number of servers using TLS_RSA_WITH_RC4_128_SHA but there is an increase (+89) in the number of servers using TLS_ECDHE_RSA_WITH_RC4_128_SHA. The move to ECDHE for key exchange is positive as it provides forward secrecy, but continued use of the RC4 as a stream cipher is a security risk and is prohibited by [31]. RC4 is no longer cryptographically secure as it is computationally feasible to crack it.

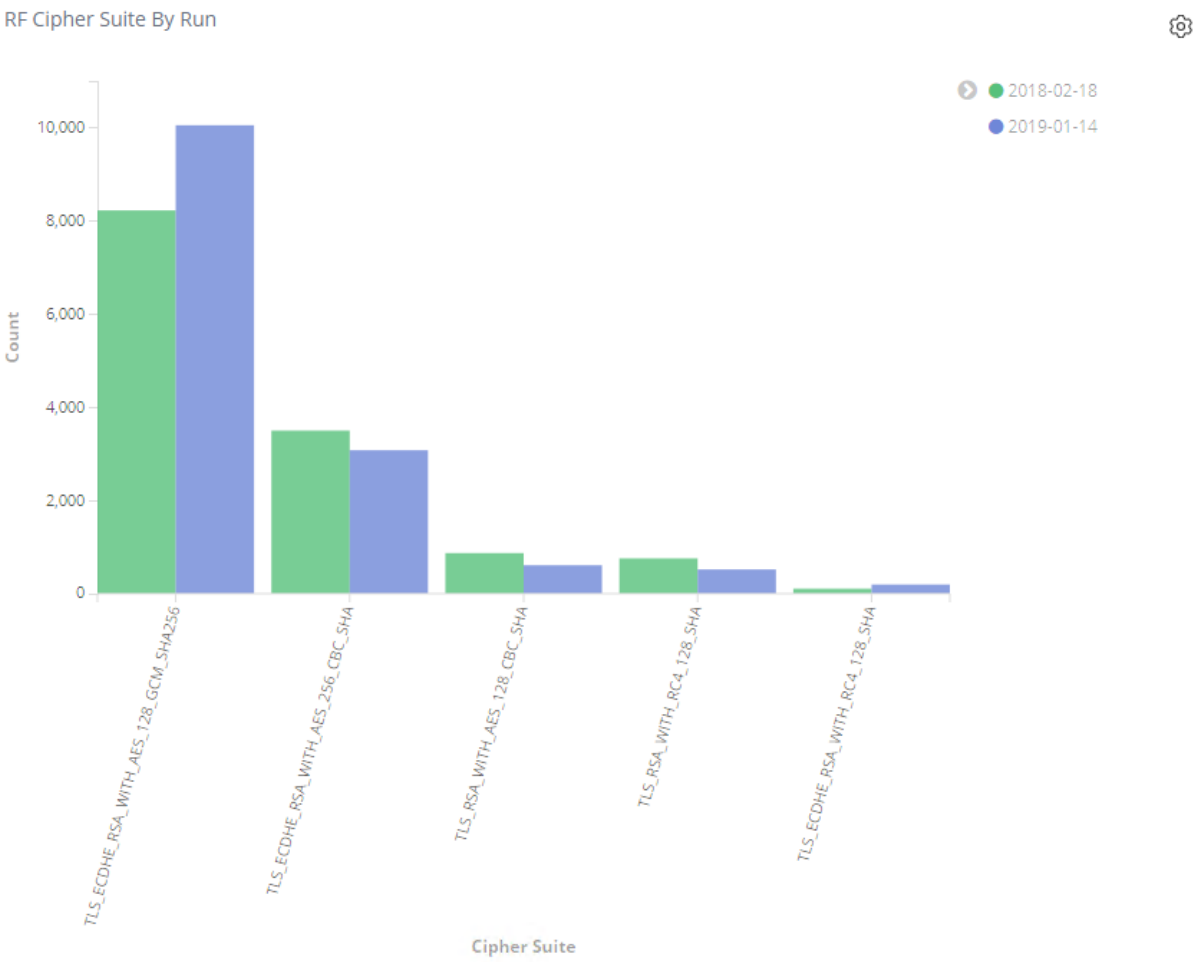

Figure 4.6: Ireland Dashboard: Count of servers by port 443 cipher suite

Figure 4.7 shows the names of the most common ASes seen in all three scans. If a server is seen in all three scans, it is counted three times. This visualisation could be particularly useful in localised scanning; it shows who the main service providers are, highlighting organisations with whom collaboration or other interaction could yield tangible results.

Figure 4.7: Ireland Dashboard: Word cloud of autonomous systems

Figure 4.8 is a heat map which shows the location of the servers from all three scans. Somewhat surprisingly, the map shows a relatively even spread of servers in most major towns and cities in Ireland, with 15-20 servers in each. Unsurprisingly, however, Dublin is by far the most common location with 26,632 servers. This stands to reason as Amazon is significantly the largest AS and its data centres are all in the Dublin region.

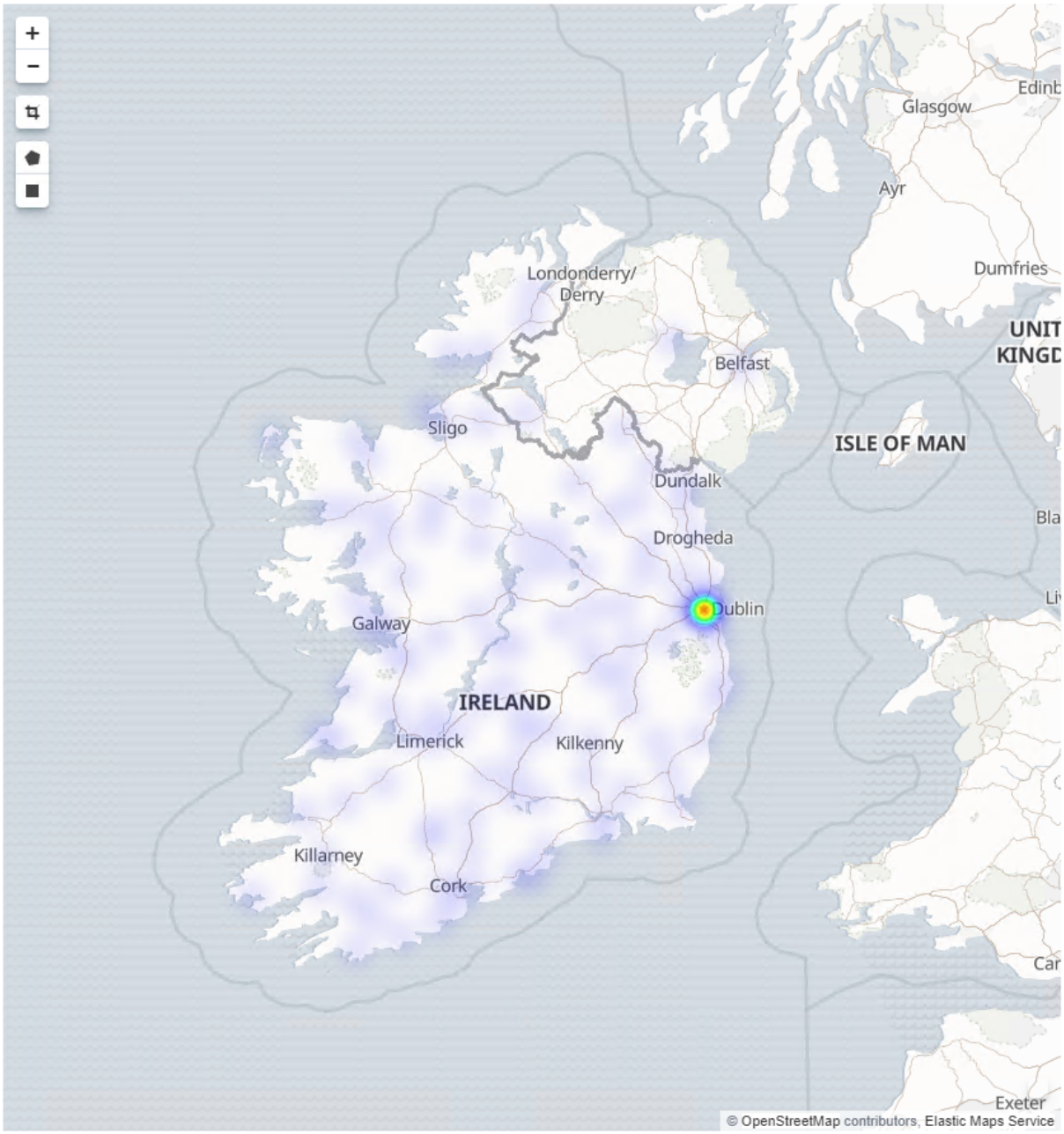

Figure 4.8: Ireland Dashboard: Geo-map of servers

4.4.2 Aviation Dashboard

The aviation dashboard shows visualisations using the three aviation data subsets.

Figure 4.9 shows the breakdown of cipher suites used by servers who share the same SHA256 fingerprint, grouped by scan date. This is the same type of visualisation described in Section 4.3.1. The graph shows that in 2018, the public key of the first fingerprint was used by 4 servers, three of whom used the TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA cipher suite and one who used TLS_RSA_WITH_AES_256_CBC_SHA. This wouldn't be of major concern as while ECDHE is stronger than RSA (provides forward secrecy), both are strong cipher suites.

The graph also shows that in 2018 the 2 servers who used the public key of the third fingerprint used TLS_RSA_WITH_AES_128_CBC_SHA but in 2019 are using TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256. Filtering the dashboard by the fingerprint shows that the two servers are in different geographic locations (Dublin and Dundalk) and have two different ASes (Eir Broadband and Liberty Global B.V.). Further investigation would be needed to determine the relation between the two servers (i.e. why the share the same public key). In this case the change is positive, but if it wasn't further investigation could be beneficial.

Figure 4.10 shows the change in the number of servers using the ten most common ASes across the three scans. It shows an increase in the number of servers using Amazon, as would be expected with the increasing popularity of cloud computing and AWS [32]. This graph, similar to the AS word cloud described previously, could be used to identify the large and upcoming service providers.

Figure 4.11 shows a map similar to the one used for the Ireland data. This map shows more precisely the location of servers.

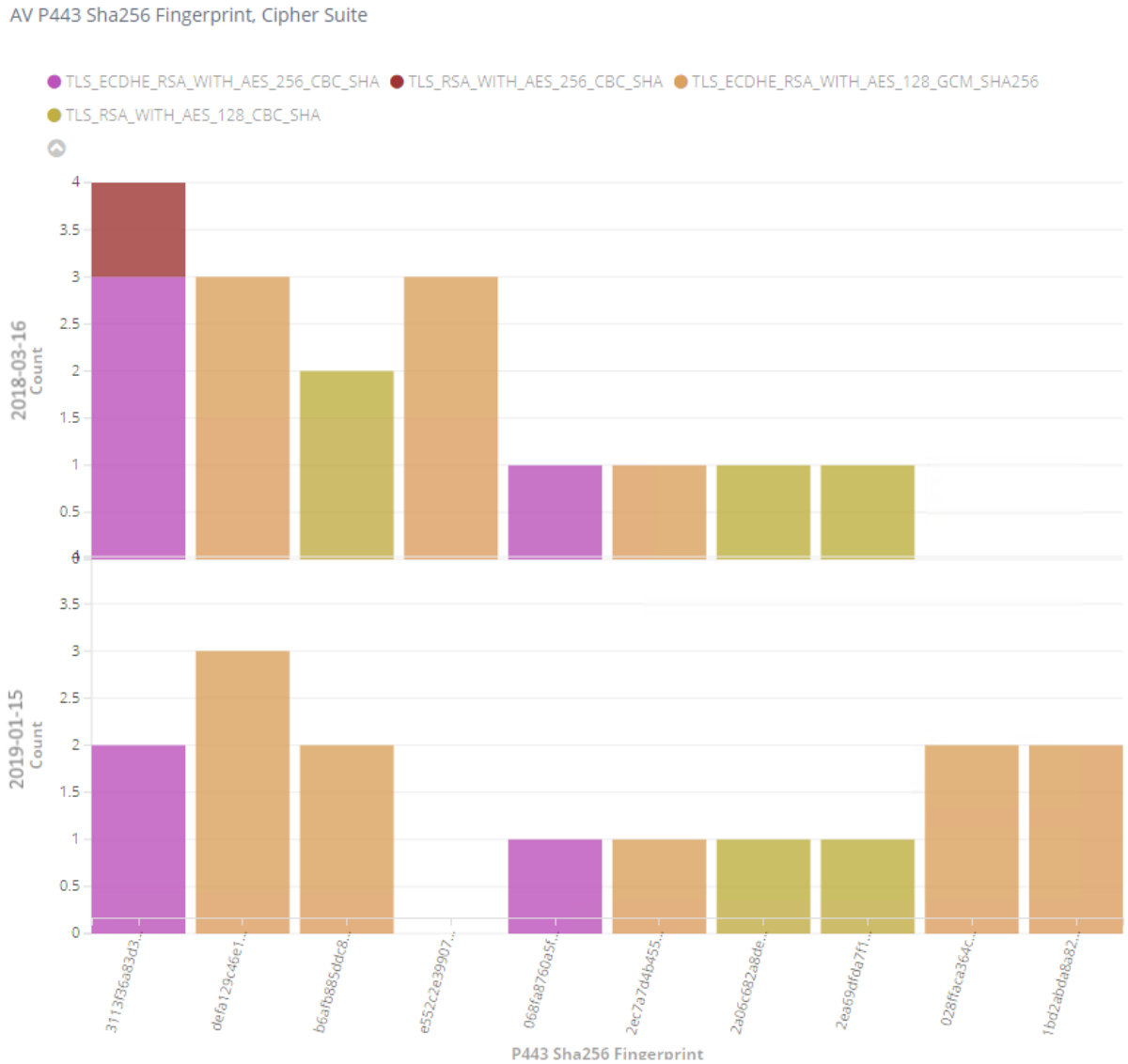

Figure 4.9: Aviation Dashboard: Count of servers by port 443 SHA256 fingerprint, cipher suite

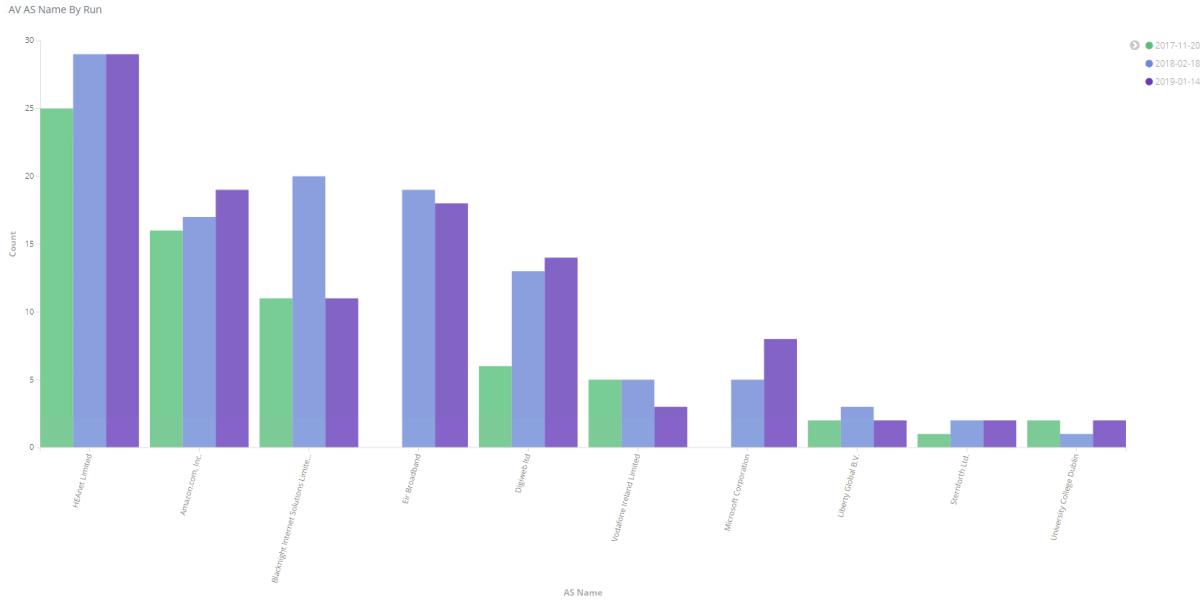

Figure 4.10: Aviation Dashboard: Count of autonomous systems by scan

Figure 4.11: Aviation Dashboard: Geo-map of servers

5 Evaluation

5.1 Comparison of JSON File versus Elasticsearch Query Code

To quantify the benefit of using Elasticsearch, several queries were performed over the 2018 Ireland data with and without using Elasticsearch. In both cases, python scripts were developed to run the queries five times to get the average time taken. The Elasticsearch python library was used to run the queries in Elasticsearch. The number of lines and readability of the code were also used to evaluate both options.

The following queries were performed:

- **Search IP:** the data was searched for a specific IP address and all matching records returned.
- **Search Fingerprint:** the data was searched for a specific port 443 SHA256 fingerprint and all matching records returned.
- **Search Fingerprint, Group Result By Cipher Suite:** the data was searched for a specific port 443 SHA256 fingerprint. All records were returned, grouped by the cipher suite used on port 443.

5.1.1 Running Time

Tables 5.1, 5.2 and 5.3 show that on average Elasticsearch was 1,100 times faster at searching the data for an IP address, 143 times faster at searching for a fingerprint and 2,000 times faster at searching for an IP address and grouping the result. In all three cases, the code which uses Elasticsearch runs in $O(1)$ time. In reality, the results are returned in near real-time. The code that uses the file performs a linear search over the entire file. It runs in $O(n)$ time, where n is the number of lines (servers) in the file.

Test	File (s)	Elasticsearch (s)
1	24.41	0.0809
2	29.03	0.0092
3	23.45	0.0089
4	30.22	0.0088
5	21.79	0.0089
Average	25.75	0.0234

Table 5.1: Comparison of time taken for "search IP" query with and without Elasticsearch. Time is measured in seconds.

Test	File (s)	Elasticsearch (s)
1	23.28	0.7755
2	24.68	0.0287
3	24.03	0.0186
4	24.44	0.0141
5	25.39	0.0146
Average	24.36	0.1703

Table 5.2: Comparison of time taken for "search fingerprint" query with and without Elasticsearch. Time is measured in seconds.

Test	File (s)	Elasticsearch (s)
1	23.62	0.0129
2	22.31	0.0109
3	23.45	0.0109
4	24.64	0.011
5	22.47	0.0107
Average	23.24	0.0113

Table 5.3: Comparison of time taken for "search fingerprint, group result by cipher suite" query with and without Elasticsearch. Time is measured in seconds.

5.1.2 Lines of Code and Code Readability

Table 5.4 shows the number of lines of code required to perform each query. As the complexity of the query increases, the lines of code required to perform the query without using Elasticsearch also increase. For simple queries, such as searching by a single field, Elasticsearch only requires three lines of code. For more complex queries, such as those using aggregations, the number of lines required increases. Technically all queries using Elasticsearch require just three lines of python code, with the remaining lines being the Elasticsearch query. This query could be written in a single line, however it would not be very readable.

Query	File (LoC)	Elasticsearch (LoC)
Search IP	7	3
Search Fingerprint	12	3
Search Fingerprint, Group By Cipher Suite	15	3 / 26

Table 5.4: Comparison of Lines of Code (LoC) needed to perform queries with and without Elasticsearch.

Readability of code is not easily quantifiable and is subject to opinion. Nonetheless it is a relevant factor when evaluating code quality. Code that is easy to read is easier to understand, debug and maintain. While the number of lines of code used with Elasticsearch is greater, it is much easier to read the code and understand what it is doing. Appendix A3 shows the code for the three queries both with and without using Elasticsearch.

5.2 Elasticsearch & Kibana Strengths and Limitations

As shown previously, there are many benefits to using Elasticsearch and Kibana. Below is a summary of some of their strengths:

- **Fast:** near real-time search with simple and moderately complex queries.
- **Scalable:** can be scaled up to millions of documents
- **Easy Visualisations:** it is quick and easy to create simple graphs for high-level data analysis.
- **Seamless Integration:** once Elasticsearch is set up, there is very little setup required to start using Kibana.

However, as with everything, they have limitations. Below are some of the weaknesses of Elasticsearch and Kibana:

- **No Joins:** Elasticsearch does not support join queries. Aggregations can be used to get similar results in some cases, but it is not always straightforward to do.
- **Documentation:** Elasticsearch is primarily used for analysing large amounts of relatively short log file entries on multi-node clusters with large amounts of RAM (32-64GB). It is also used for catalogue searching and providing recommendations. Again, the documents are relatively short in this case. This project used Elasticsearch for analysing small amounts of large documents (up to 3,000 fields per document) on a single node cluster with 2GB RAM. While Elasticsearch can be used for the latter, as demonstrated in this project, most of the documentation and help available is focused

on the former use cases. As a result, challenges such as the one described in Section 3.4.1 took longer to resolve.

- **Limited Native Visualisations:** while it is easy to create simple visualisations in Kibana, it is limited when performing more complex analysis. For example, finding key re-use clusters as in [8]. There are graphing tools for Kibana which may be able to do such analysis, however they are not available in the open source version.

6 Conclusion

A number of goals were set in Section 1.1 to provide guidance throughout the project and to provide a means to determine the success of the project at the end. This chapter discusses the latter.

Elasticsearch was successfully implemented as a data store, as shown in Section 3.5. As well as simply storing schema-less JSON data as many NoSQL databases can do, it also supports full-text search in near real-time.

The CLI tool described in Section 3.3 provides an easy way to ingest scan data. It can easily be used both interactively and as part of a script. It is memory efficient and, if running on the same machine as Elasticsearch, checks if Elasticsearch has crashed while inserting data and if it has restarts it.

Kibana can be used to rapidly create visualisations and perform high-level data analysis, as shown in Chapter 4. It is also easy to query data in Elasticsearch programmatically, as shown in Section 5.1. This allows more complex analysis of the data.

All Elasticsearch and Kibana features used in this project are available in the open-source versions. All libraries used in developing the CLI tool are also open-source.

The machine used throughout the development and testing of this project had limited resources available. While this presented challenges, outlined in Section 3.4.1, they were successfully resolved. Elasticsearch has built-in support for horizontal scaling out to hundreds of nodes. It automatically takes care of replication and failover when configured.

The CLI tool can be used to install and configure Elasticsearch and Kibana in a production environment. Section 3.4.1 provides some recommendations on choosing the correct heap size, number of shards and number of indices. Section 4.1 outlines how Kibana was securely accessed remotely for this project, which could be used for guidance.

In conclusion, this project met all the goals set out in Section 1.1. It used the Elastic Stack to provide data storage, analysis and visualisation functionality. The issues described in Section 3.4.1 and the weaknesses outlined in Section 5.2 resulted in less time available for more detailed data analysis. It was hoped that the code used in [8] would be re-implemented

using Elasticsearch to evaluate it when performing more complex analysis. However, due to time constraints this was not possible.

7 Future Work

7.1 Integration With Scanning

This project was developed independently from the scanning tools. The results of scans are saved to a file. The tools developed in this project allow these files, as well as any files containing JSON objects, to be imported into Elasticsearch. However, this import takes time. Instead of (or as well as) being saved to a file, the results of the scan could be sent directly to Elasticsearch. Results for each server scanned would be sent as soon as all ports were scanned for that server. Partial data analysis and visualisation could be performed while the scan is still running.

Developing such integration was briefly considered during this project but the hardware infrastructure used prohibited it given the time available. The machine used for scanning was an internet-facing machine. The machine running the Elastic Stack was an internal machine, only accessible from within the Trinity College network. A secure link for the scanning machine to connect to Elasticsearch would be needed.

7.2 Data Transformations

Currently, the entire output of the ZGrab scans are stored in Elasticsearch. It may be possible to discard fields which aren't useful for analysis. This would reduce the overhead in Elasticsearch of storing fields. It would improve performance both when inserting and retrieving data. It may also be useful to do data transformation to make the data easier to work with, such as with ZTag. The current documents have a high level of nesting which can make field names very long when performing queries.

7.3 Complex Analysis

All analysis performed during this project involved simple - moderate queries. The Kibana visualisations provide a high-level overview of the data. To find out if actual security or privacy issues exists, and if so what mitigations are needed, the data needs to be analysed in more depth. The issue of key re-use described in [8] is such an example. The analysis couldn't be done in Kibana or using a single Elasticsearch query and would require external code. It is expected that such code would be much simpler if Elasticsearch was used, but further investigation would be required to verify this.

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A1 Appendix: Sample Scan Data


```
{
    "p110": {
        "ip": "46.22.131.1",
        "data": {
          "tls": {...},
          "banner":
           ↪  "+OK Dovecot ready. <790e.4.5aae8023.ojSEOG8vUM8cFnhdlFHL2w==@cloudvm.shadestudio.ie>
           ↪  ,
          "starttls": "+OK Begin TLS negotiation now.\r\n"
        },
        "timestamp": "2018-03-18T15:05:07Z"
      },
      "country_code": "IE",
      "run_date": "2018-03-16",
      "ip": "46.22.131.1",
      "average": 8.552224866987988,
      "writer": "FreshGrab.py",
      "domain": "ari.ie",
      "asn": "Blacknight Internet Solutions Limited",
      "p25": {
        "ip": "46.22.131.1",
        "data": {
          "ehlo":
           ↪  "250-cloudvm.shadestudio.ie\r\n250-PIPELINING\r\n250-SIZE 30720000\r\n250-ETRN\r\n250
           ↪  ,
          "tls": {...},
          "banner": "220 cloudvm.shadestudio.ie ESMTP Postfix\r\n",
          "starttls": "220 2.0.0 Ready to start TLS\r\n"
        },
        "timestamp": "2018-03-18T15:05:06Z"
      },
      "p993": {
        "ip": "46.22.131.1",
        "data": {
          "tls": {...},
```

```
      "banner":
       ↪  "* OK [CAPABILITY IMAP4rev1 LITERAL+ SASL-IR LOGIN-REFERRALS ID ENABLE IDLE AUTH=PLAI
    },
    "timestamp": "2018-03-18T15:05:10Z"
  },
  "p143": {
    "ip": "46.22.131.1",
    "data": {
      "tls": {...},
      "banner":
       ↪  "* OK [CAPABILITY IMAP4rev1 LITERAL+ SASL-IR LOGIN-REFERRALS ID ENABLE IDLE STARTTLS
       ↪  ,
      "starttls": "a001 OK Begin TLS negotiation now.\r\n"
    },
    "timestamp": "2018-03-18T15:05:08Z"
  },
  "geoip": {
    "location": {
      "lat": 53.3472,
      "lon": -6.2439
    }
  },
  "asndec": 39122,
  "p587": {
    "ip": "46.22.131.1",
    "data": {
      "ehlo":
       ↪  "250-cloudvm.shadestudio.ie\r\n250-PIPELINING\r\n250-SIZE 30720000\r\n250-ETRN\r\n250
       ↪  ,
      "tls": {},
      "banner": "220 cloudvm.shadestudio.ie ESMTP Postfix\r\n",
      "starttls": "220 2.0.0 Ready to start TLS\r\n"
    },
    "timestamp": "2018-03-18T15:05:09Z"
  },
  "p22": {
    "ip": "46.22.131.1",
    "data": {
      "xssh": {...}
    },
    "timestamp": "2018-03-18T15:05:06Z"
  },
  "duration": 5.213533163070679,
  "company": "Aer Rianta International",
  "p443": {
    "ip": "46.22.131.1",
```

```
        "data": {
          "http": {
            "response": {
              "body": "",
              "content_length": 225,
              "protocol": {
                "major": 1,
                "name": "HTTP/1.1",
                "minor": 1
              },
              "headers": {...},
              "status_code": 301,
              "status_line": "301 Moved Permanently",
              "request": {
                "url": {
                  "path": "/",
                  "host": "46.22.131.1:443",
                  "scheme": "https"
                },
                "headers": {...},
                "host": "46.22.131.1",
                "tls_handshake": {
                  "server_key_exchange": {
                    "ecdh_params": {
                      "server_public": {
                        "y": {
                          "length": 256,
                          "value": "LxV/GH/bPTCkJluneefkvQEX83QAJ6ZYhxVEbVJk3GQ="
                        },
                        "x": {
                          "length": 256,
                          "value": "/w9cDEzrsEAoOnTlrr1odL+PUg+IXhxBEXU8owO2MY4="
                        }
                      },
                      "curve_id": {
                        "id": 23,
                        "name": "secp256r1"
                      }
                    },
                    "signature": {
                      "raw":
                       ↪  "EADHcsgVXQ0QcMxn2z0UFyn/SnvzGnY2J/DYvPt8PpNrWLOdkqd3uqtjWrgheudxpsoqWdVL
                       ↪  ,
                      "tls_version": {
                        "name": "TLSv1.2",
                        "value": 771
```

```
        },
        "valid": true,
        "type": "rsa",
        "signature_and_hash_type": {
          "hash_algorithm": "sha256",
          "signature_algorithm": "rsa"
        }
      }
    },
    "server_certificates": {
      "validation": {
        "browser_trusted": false,
        "browser_error": "x509: unknown error"
      },
      "certificate": {...},
    "key_material": {
      "pre_master_secret": {
        "length": 32,
        "value": "zPOAFbUEGXvXaFHTCnz4689Zt5+6x38tMejfafKi3Zk="
      },
      "master_secret": {
        "length": 48,
        "value":
         ↪  "FegsMDh6+TCEY2camTlfpNV3rOZgqPhWFF2ozUmeSHMzYhfEaIrN18o5UMxxy8l/"
      }
    },
    "server_finished": {
      "verify_data": "AzZLN9SCiDI0Oqx8"
    },
    "client_hello": {
      "sct_enabled": false,
      "next_protocol_negotiation": false,
      "compression_methods": [
        {
          "hex": "0x00",
          "name": "NULL",
          "value": 0
        }
      ],
      "secure_renegotiation": true,
      "cipher_suites": [
        {
          "hex": "0xC02F",
          "name": "TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256",
          "value": 49199
        },
```

```
                    {
                      "hex": "0xC02B",
                      "name": "TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256",
                      "value": 49195
                    },
                    {
                      "hex": "0xC011",
                      "name": "TLS_ECDHE_RSA_WITH_RC4_128_SHA",
                      "value": 49169
                    },
                    {
                      "hex": "0xC007",
                      "name": "TLS_ECDHE_ECDSA_WITH_RC4_128_SHA",
                      "value": 49159
                    },
                    {
                      "hex": "0xC013",
                      "name": "TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA",
                      "value": 49171
                    },
                    {
                      "hex": "0xC009",
                      "name": "TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA",
                      "value": 49161
                    },
                    {
                      "hex": "0xC014",
                      "name": "TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA",
                      "value": 49172
                    },
                    {
                      "hex": "0xC00A",
                      "name": "TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA",
                      "value": 49162
                    },
                    {
                      "hex": "0x0005",
                      "name": "TLS_RSA_WITH_RC4_128_SHA",
                      "value": 5
                    },
                    {
                      "hex": "0x002F",
                      "name": "TLS_RSA_WITH_AES_128_CBC_SHA",
                      "value": 47
                    },
                    {
```

```
            "hex": "0x0035",
            "name": "TLS_RSA_WITH_AES_256_CBC_SHA",
            "value": 53
          },
          {
            "hex": "0xC012",
            "name": "TLS_ECDHE_RSA_WITH_3DES_EDE_CBC_SHA",
            "value": 49170
          },
          {
            "hex": "0x000A",
            "name": "TLS_RSA_WITH_3DES_EDE_CBC_SHA",
            "value": 10
          }
        ],
        "random": "2WCsuSjVsGLT8JuEbE2juu7xqr9Thx4bcsSvUDEWvVo=",
        "extended_master_secret": false,
        "supported_curves": [
          {
            "hex": "0x0017",
            "name": "secp256r1",
            "value": 23
          },
          {
            "hex": "0x0018",
            "name": "secp384r1",
            "value": 24
          },
          {
            "hex": "0x0019",
            "name": "secp521r1",
            "value": 25
          }
        ],
        "supported_point_formats": [
          {
            "hex": "0x00",
            "name": "uncompressed",
            "value": 0
          }
        ],
        "ocsp_stapling": true,
        "version": {
          "name": "TLSv1.2",
          "value": 771
        },
```

```
                    "scts": false,
                    "heartbeat": false,
                    "server_name": "46.22.131.1",
                    "signature_and_hashes": [
                      {
                        "hash_algorithm": "sha256",
                        "signature_algorithm": "rsa"
                      },
                      {
                        "hash_algorithm": "sha256",
                        "signature_algorithm": "ecdsa"
                      },
                      {
                        "hash_algorithm": "sha1",
                        "signature_algorithm": "rsa"
                      },
                      {
                        "hash_algorithm": "sha1",
                        "signature_algorithm": "ecdsa"
                      }
                    ],
                    "ticket": false
                  },
                  "client_finished": {
                    "verify_data": "hBxuak5im3+aFRes"
                  },
                  "server_hello": {
                    "compression_method": 0,
                    "secure_renegotiation": true,
                    "random": "Wq6AJF5lmkDPtAC5Ij4juKeFDcUW9CaoK5d3RrK0FHk=",
                    "extended_master_secret": false,
                    "session_id": "xEDc+coVcHSk6Sw2vXqK9clWarx1w1I8ATMWPyjcLKg=",
                    "cipher_suite": {
                      "hex": "0xC014",
                      "name": "TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA",
                      "value": 49172
                    },
                    "version": {
                      "name": "TLSv1.2",
                      "value": 771
                    },
                    "ocsp_stapling": false,
                    "heartbeat": false,
                    "ticket": false
                  },
                  "client_key_exchange": {
```

```
                    "ecdh_params": {
                      "curve_id": {
                        "id": 23,
                        "name": "secp256r1"
                      },
                      "client_public": {
                        "y": {
                          "length": 256,
                          "value": "xZq/SxhV2oJE6ooTxb8telkBn1lnbfh7KjYabQikxmQ="
                        },
                        "x": {
                          "length": 256,
                          "value": "qU+RYs7fOgrfpSYbf/hMacp5GcZBk43QbicOuTOSJWg="
                        }
                      },
                      "client_private": {
                        "length": 32,
                        "value": "oab4AZ4gSRwaxwpNbKqrT7M5x+phdu43GifPKENfrhA="
                      }
                    }
                  }
                },
                "method": "GET"
              },
              "body_sha256":
               ↪  "9caabeac0187489627b5f6caeadc91a8ee165a3dcee01b8a316d160b53d429d5"
            }
            ]
          }
        },
        "timestamp": "2018-03-18T15:05:08Z",
        "error": "Get http://bavari.ie/: stopped after 0 redirects"
        }
      }
}
```

A2 Appendix: Sample Elasitcsearch Query

A2.1 Servers By Fingerprint, Cipher Suite, Run Date Query

```
{
  "aggs": {
    "fingerprint": {
      "terms": {
        "field": "doc.p443.data.http.response.request.tls_handshake
                    .server_certificates.certificate.parsed
                    .subject_key_info.fingerprint_sha256.keyword",
        "size": 15,
        "order": {
          "_count": "desc"
        }
      },
      "aggs": {
        "cipherSuite": {
          "terms": {
            "field": "doc.p443.data.http.response.request.tls_handshake
                        .server_hello.cipher_suite.name.keyword",
            "size": 15,
            "order": {
              "_count": "desc"
            }
          },
          "aggs": {
            "scanDate": {
              "date_histogram": {
                "field": "doc.run_date",
                "interval": "30d",
```

```
                "time_zone": "Europe/London",
                "min_doc_count": 1
              }
            }
          }
        }
      }
    },
    "size": 0,
    "query": {
      "bool": {
        "must": [
          {
            "match_all": {}
          }
        ]
      }
    }
}
```

A2.2 Servers By Fingerprint, Cipher Suite, Run Date Partial Result

```
{
  "took" : 1411,
  "timed_out" : false,
  "_shards" : {
    "total" : 3,
    "successful" : 3,
    "skipped" : 0,
    "failed" : 0
  },
  "hits" : {
    "total" : 75434,
    "max_score" : 0.0,
    "hits" : [ ]
  },
  "aggregations" : {
    "fingerprint" : {
      "doc_count_error_upper_bound" : 7,
      "sum_other_doc_count" : 5656,
```

```
      "buckets" : [
        {
          "key" : "9f0050378fa2a1389b35cf74e0f1063ad42eaebc5a324b10c6aacf3ab08f7a94",
          "doc_count" : 22,
          "cipherSuite" : {
            "doc_count_error_upper_bound" : 0,
            "sum_other_doc_count" : 0,
            "buckets" : [
              {
                "key" : "TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA",
                "doc_count" : 14,
                "scanDate" : {
                  "buckets" : [
                    {
                      "key_as_string" : "2018-02-18T00:00:00.000Z",
                      "key" : 1518912000000,
                      "doc_count" : 8
                    },
                    {
                      "key_as_string" : "2019-01-14T00:00:00.000Z",
                      "key" : 1547424000000,
                      "doc_count" : 6
                    }
                  ]
                }
              },
              {
                "key" : "TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256",
                "doc_count" : 4,
                "scanDate" : {
                  "buckets" : [
                    {
                      "key_as_string" : "2018-02-18T00:00:00.000Z",
                      "key" : 1518912000000,
                      "doc_count" : 3
                    },
                    {
                      "key_as_string" : "2019-01-14T00:00:00.000Z",
                      "key" : 1547424000000,
                      "doc_count" : 1
                    }
                  ]
                }
              },
              {
                "key" : "TLS_RSA_WITH_AES_256_CBC_SHA",
```

```
                "doc_count" : 4,
                "scanDate" : {
                  "buckets" : [
                    {
                      "key_as_string" : "2018-02-18T00:00:00.000Z",
                      "key" : 1518912000000,
                      "doc_count" : 1
                    },
                    {
                      "key_as_string" : "2019-01-14T00:00:00.000Z",
                      "key" : 1547424000000,
                      "doc_count" : 3
                    }
                  ]
                }
              }
            ]
          }
        }
      ]
    }
  }
}
```

A3 Appendix: Evaluation Queries

A3.1 Search IP

```
# Using file
def searchIp(ip):
    result=[]
    with open(infile,'r') as f:
        for line in f:
            j_content = json.loads(line)
            if (j_content['ip']==ip):
                result.append(j_content)
    return result

# Using Elasticsearch
def searchIp(ip):
    query = "doc.ip: {}".format(ip)
    result = es.search(index = index, q=query)
    return result
```

A3.2 Search Fingerprint

```
# Using file
def searchP443Fingerprint(fp):
    result=[]
    with open(infile,'r') as f:
        for line in f:
            j_content = json.loads(line)
            fprint=""
            try:
                fprint = j_content['p443']['data']['http']['response']['request']
                ↪  ['tls_handshake']['server_certificates']['certificate']['parsed']
                ↪  ['subject_key_info']['fingerprint_sha256']
```

```
            except:
                pass
            if (fprint and fprint==fp):
                result.append(j_content)
    return result

# Using Elasticsearch
def searchP443Fingerprint(fp):
    query = "doc.p443.data.http.response.request.tls_handshake.server_certificates
    ↪  .certificate.parsed.subject_key_info.fingerprint_sha256.keyword:
    ↪  {}".format(fp)
    result = es.search(index = index, q=query)
    return result
```

A3.3 Search Fingerprint, Group Result By Cipher Suite

```
# Using file
def searchP443FingerprintGroupByCipherSuite(fp):
    result={}
    with open(infile,'r') as f:
        for line in f:
            j_content = json.loads(line)
            fprint=""
            try:
                fprint = j_content['p443']['data']['http']['response']['request']
                ↪  ['tls_handshake']['server_certificates']['certificate']['parsed']
                ↪  ['subject_key_info']['fingerprint_sha256']
            except:
                pass
            if (fprint and fprint==fp):
                cipherSuite = j_content['p443']['data']['http']['response']
                ↪  ['request']['tls_handshake']['server_hello']['cipher_suite']
                ↪  ['name']
                if not cipherSuite in result:
                    result[cipherSuite]=[]
                result[cipherSuite].append(j_content)
    return result

# Using Elasticsearch
def searchP443FingerprintGroupByCipherSuite(fp):
    body={
        "query": {
```

```
            "bool": {
                "must": [
                    {
                        "query_string": {
                            "query":
                             ↪  "doc.p443.data.http.response.request.tls_handshake
                             ↪  .server_certificates.certificate.parsed
                             ↪  .subject_key_info.fingerprint_sha256.keyword: {}"
                             ↪  .format(fp)
                        }
                    }
                ]
            }
        },
        "aggs": {
            "cipherSuite": {
                "terms": {
                    "field": "doc.p443.data.http.response.request.tls_handshake
                     ↪  .server_hello.cipher_suite.name.keyword",
                    "size": 100,
                    "order": {
                        "_count": "desc"
                    }
                }
            }
        }
    }
    result = es.search(index = index, body=body)
    return result
```

A4 Appendix: Source Code

The attached DVD contains the following:

- The source code for the CLI tool.
- Scripts used to evaluate Elasticsearch.
- Configuration files for Elasticsearch.
- Export of all Kibana objects (index patterns, dashboards and visualisations).