Cloud-Based Protocol IDS using Apache Kafka and Spark Streaming

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*Abstract*—In the current era of technological advancements web applications are a major medium in the internet world. Many of these mentioned web applications adopt the usage of a dedicated back-end server where most of the technical processes happen. Typically the front-end sends requests to the back-end which can be done in multiple ways including, GraphQL, gRPC, REST, etc. In this particular paper, the focus is on REST as it is still considered a norm in most web applications. In REST, HTTP requests by the front-end which are mapped to GET, POST, PUT, and DELETE have been proven to be prone to attacks and exploits that can inflict extensive amounts of damage to a system. Therefore, this paper’s main point will be the detection of such attacks and exploits, mainly being Automated Brute Forcing on web-based login, HTTP flood attacks, a), Cross-Site Scripting (XSS). Both Apache Kafka and Spark streaming are used as main pillars in the architecture for processing the user inputs in REST HTTP header fields, which are the main vulnerabilities that are being exploited in such attacks. As HTTP requests from the front end of a web application come in massive volumes it is crucial to process these HTTP requests in an efficient and resourceful way. Spark streaming allows both of these critical processing characteristics by using batch processing and MapReduce. Apache Kafka allows back-end engineers to send real-time request logs to a Kafka broker and furthermore bridges the streamed data to Spark streaming using the Spark Streaming & Kafka Integration library. In this paper algorithms that were developed in Scala are used to determine if an HTTP request contains any patterns that resemble any of the 4 mentioned attacks and both send an alert to the system security engineer and log the event in a Google Cloud Storage Bucket, as the developed IDS is implemented in Google Cloud Platform.

Keywords—Intrusion Detection, Apache Kafka, Spark Streaming, SQL injection, Cross-site scripting, Brute Force Login, HTTP flood attacks

# Introduction

An Intrusion detection system is a security system which main functionality is the monitoring and analysis of system events for the purpose of finding and providing real-time or near real-time alerts and warnings of attempts of unauthorized access to system resources. Protocol-based intrusion detection systems are specialized IDSs that are commonly installed on web servers and used to exclusively monitor and analyze HTTP or HTTPS requests in a stream-like format. There are three types of intrusion detections methods, which are as follows:

i) Signature/Heuristic-based detection, which is a simple and efficient method of detection that involves the matching against large collections of rules or known patterns of malicious data. Nevertheless, the ability of an IDS that uses this method to correctly detect an intrusion solely depends on the available collection of signatures. Hence, the system cannot detect unknown intrusions in which patterns are not contained in the collection of signatures.

ii) Anomaly-based detection, which involves actual observations is more dynamic and more intelligent compared to the latter. Using either statistical methods or Machine-learning are used to analyze events and categorize them into either being a legitimate request or an intrusion attempt. Statistical methodologies are applied to observe the behavior of events using univariate, multivariate, or time-series models to observe measurable metrics. The Machine-learning approach uses Classification ML models, which work by intaking events and activities and classifying them into being either intrusion attempts or not, as has been done in [3]. Additionally, more advanced ML models can classify events into more than two classes as in [11], where Siva Reddy and Saravanan have developed multiple Classification Models with more than 2 variations of outputs using one-hot encoding. Regardless of the mentioned advantages, compared to Signature/Heuristic-based detection, Anomaly-based detection’s performance is not as favorable and has some effects on less powerful machines running real-time IDS.

iii) Distributed/Hybrid-based detection, which performs using a combination of Signature/Heuristic-based detection and Anomaly-based detection. This detection method has a more complex structure, but with it comes a better identification rate and response time.

A good intrusion detection system including protocol intrusion detection systems should give results in a real-time manner, must not take up a lot of resources, have a low false positive and false negative rate, have high to permanent uptime, and cover a wide area of intrusion methods that it can detect. But for protocol intrusion detection systems, it is difficult to achieve the characteristic of not using up a lot of resources because medium-sized to mainstream-sized web applications have a massive amount of HTTP requests that are sent at all times. Applying any kind of algorithm efficiently has always been a challenge, which this paper will be tackling. Furthermore, the problem of having permanent uptime on an on-premise IDS is not guaranteed, as it is an apparent problem that comes with every system that is on-premise due to power or internet outage, natural disasters, etc.

This paper’s IDS is a cloud-based protocol IDS, which means that it is a protocol IDS that runs on a cloud environment, specifically Google Cloud Platform (GCP) [21]. This solves the problem of the lack of guarantee when talking about the uptime which should be high enough to a certain degree. Google Cloud Platform’s service level agreement (SLA) dictates that the services that the system uses have a corresponding uptime being:

1. Compute Engine single instance SLA Monthly Uptime percentage of
2. Cloud Storage in regional location SLA Monthly Uptime percentage of
3. Dataproc SLA Monthly Uptime percentage of

This allows the system to run almost permanently as the lowest SLA is 99.5% per month. The problem of huge amounts of streaming data, which needs to be processed in an efficient way, which comes with being a Protocol IDS is also being approached with the combination of using Apache Kafka [20] and Spark Streaming [19]. Kafka acts as the receiving end of a bridge that allows all the streaming data to pass through via four separate topics in a broker, being GET, POST, PUT, and DELETE, which correspond to their actual HTTP method name. These four topics, which are streaming data are then sent to separate Spark Streaming jobs that each detect their own Intrusions namely:

1. Automated Brute Forcing on web-based login
2. HTTP flood attacks
3. SQL Injections (SQLi)
4. Cross-Site Scripting (XSS)

Spark Streaming is a framework that works on Spark; therefore, it utilizes parallel computation and synchronization of multiple machines on one or more clusters. Dividing Streaming data into batches by time frames allows the usage of batch processing, furthermore the creation of a specialized Data structure called Resilient Distributed Dataset (RDD). Algorithms created in Spark typically run MapReduce Jobs which have been proven to give tremendous amounts of resource utilization and efficiency, which can be backed by Tun’s, Nyaung’s, and Phyu’s experimentation results in [12], which show that 500,000 records as one batch can be processed in around 0.5 to 1.2 seconds using medium computation power, being an Intel Core i5 processor and 8GB memory.

Automated Brute Forcing [1] on web-based login is the act of using a program or script to forcefully send login requests, typically GET requests in HTTP to a web server. The frequency of requests sent varies from program to program and machine sent from. The Automated Brute Force Login detection algorithm alerts and logs requests if a certain request limit threshold is breached from a single IP address attempting to send requests at a high frequency. HTTP flood attacks are similarly detected using a different algorithm. Since HTTP flood attacks originate from all four HTTP request methods, being GET, POST, PUT, and DELETE, all requests are being processed in the HTTP flood attack detection algorithm. The frequency counting part also remains the same with the exception of the request frequency limit which is dependent on the implementation of IDS itself. As for SQL injections and Cross-Site Scripting detection, both have algorithms that function closely. A list of sub-strings for each attack is constructed which are extracted from datasets [16] [17], which are most likely to occur in an attack attempt.

The main objective of this paper is to show the capabilities of Apache Kafka and Spark streaming when used as a Protocol IDS to detect the aforementioned attacks while describing the architecture and methods used in detail with their corresponding results. Moreover, this paper’s architecture can be used as a foundation for more specialized implementation in the Future.

# Related Work

In 2020 Hai and Khiem [4] proposed an architecture for processing IDS logs using Spark Streaming. The focus is to improve the performance of Network Intrusion Detection Systems (N-IDS) by using distributed processing and parallel computing with Apache Spark. Three distributed computing models are compared with, being:

#### Distributed Snort

#### HBase & Impala

#### HBase & Impala & Additional VM.

#### The computational efficiency is best in point iii), as HBase & Impala have been shown to have higher throughput, adding more VMs, which do not only increase computational power but also add additional space, therefore being more powerful. This inspired the usage of using a distributed system to efficiently process the great number of requests that are poured into the system.

This concept is then further built on by the system built-in [12], which is used to evaluate the performance and has presented promising results when it comes to huge amounts of records. In this system 100,000, 300,000, and 500,000 records have been used as a testing load for a 1-time frame. These records are sent to Spark streaming via Apache Kafka, which this paper’s architecture has fully adopted. The results of the experimentations indicate that performance issues do not occur even if the amount of records fed into the system is immense. This allows the implementation of this paper’s protocol IDS to be more realistic as many back-end frameworks have implemented Apache Kafka in their language and can be used to send streaming data from their web application to the IDS which is hosted on the cloud.

Furthermore, in the year 2021 Elmasry, Akbulut, and Zaim [14] proposed a design of integrated cloud-based intrusion detection systems (CIDS) using third-party cloud service. This design integrates all of the modules that are used in an IDS to be migrated and fully used in a third-party cloud environment, where the operations of Monitoring, Processing, Analysis, Prediction, and Response are accomplished on the cloud. This configuration’s purpose is explained to have a more resourceful computation and higher uptime during the Processing and Analysis compared to the normal system that is on-premise. Elmasry’s, Akbulut’s, and Zaim’s modules have been partially implemented and mapped into this paper. The Monitoring Module is depicted as the Kafka broker, which receives data streams from the four producers depending on the HTTP request method. The Processing and Analysis Module are mapped to the four Spark Jobs which contain algorithms to detect intrusions. The final module this paper implements is the Alert module which consists of an embedded Vonage API call for each Spark Job accompanied by the logs that are saved on a dedicated Google Cloud Storage bucket.

This paper’s source code is heavily influenced by an Open Source GitHub project made by Xu [15]. Visor which is a real-time log monitoring program using Kafka is used to log HTTP requests in a special format, which can be seen in Figure aa.

Figure aa: Log Pattern of HTTP requests

This real-time log monitoring system is the basis of this paper’s streaming data input and format. Apache Kafka takes in or digests these requests from producers to topics according to HTTP request methods and then relays them to consumers that specifically request these topics.

Debnath et al [10] have conceived a model for Real-time Log Analysis System called LogLens. The Dynamic Programming Algorithm is used to detect abnormal log sequences of an event or transaction. This Algorithm goes through different parts of a log’s entry and checks important parameters against a deterministic value, String, pattern, or Wildcard. This idea is applied in this paper’s algorithm for detecting SQL Injections and Cross-Site Scripting, where collections of Wildcards are used to compare patterns or signatures that fall under each category.

The detection mechanism is placed in a matter where the actual request does not have to be forwarded to the system as the requests can be first sent to the Kafka broker before actually sending any real requests to the back end system, except for Cross-Site Scripting which is affecting the front-end part of the architecture of an application. This design choice has been proposed by Joshi, Ravishankar, Raju, and Rave [6] in 2017. Having the requests being processed and analyzed before relaying them to their actual destination increases the chance of taking action by another system or entity. In [6] it is explained that rather than having requests that may contain SQL injections being sent directly to a database, it will give a higher probability of preventing or taking action short after an attack if the system can give an output fast enough. A second part of the proposed system also includes the insertion of cross-site scripting detection before loading into the requested web page. Comparatively to the SQL injection detection’s module position, Cross-site Scripting detection can be accomplished before the new page has loaded in. The reason remains the same as for the position of the SQL injection detection module, which is to prevent or take precautions shortly after Cross-site scripting has been attempted.

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*a**b* 

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An excellent style manual for science writers is [7].

# Methodology

Figure sd System diagram

Figure sd illustrates how the system works. Our system works entirely on the Google Cloud Platform [21], starting from query requests directly from the web server by Apache Kafka. Figure aa shows a request template that will be queried by Apache Kafka.

Figure aa : Request Template

Apache Kafka then splits the request into four topics, GET, POST, PUT, and DELETE, depending on the header type of each request. The request string is then sent to Spark Streaming running on the Google Dataproc cluster [22]. Google Dataproc allows users to create different cluster types and versions. This project uses a single node master on Debian 10, Hadoop 3.2, and Spark 3.1. A single node master provides a single node that acts as both a master and a worker.

Internal Spark Streaming is divided into four jobs: Automated Brute Forcing on web-based login job, HTTP flood attacks job, SQL Injections (SQLi) job, and Cross-Site Scripting (XSS) job, which will be operated on the Debian cluster. The output of each Spark Streaming job will be stored as a log file in the bucket on Google Cloud Storage. In addition, we use the SMS API Vonage for SMS notifications [23].

### Automated Brute Forcing on web-based login Algorithm

With an Automated Brute Forcing on web-based login, the system is attacked with the GET command, so it filters only the GET Kafka topic. Use the flatmap command to split the request stream into parts. Figure 1a shows the request string split by Flatmap.

flatmap(\_.value().split(“, ”))

Figure 1a : Request string after flatmap.

The algorithm keeps track of the number of IP addresses attempted in a particular time period. If the specified threshold is exceeded, it is considered a brute force attack and the algorithm saves the IP address and the number of attempts in a log file according to [5] [7]. Figure 1b shows examples of malicious IP addresses and the number of attempts for both Automated Brute Forcing on web-based login and HTTP flood attacks.

filter(\_.contains(“ip”)).map(rdd => (rdd, 1)).reduceByKey((x, y)=> x+y).filter(x => x.\_2 > requestThreshold)

Figure 1b : Examples of Automated Brute Forcing on web-based login and HTTP flood attack’s saved IP addresses and the number of attempts.

### HTTP flood attacks Algorithm

For the HTTP flood attacks algorithm, the system is attacked with the GET, POST, PUT, and DELETE commands, so it uses every Kafka topic. Similar to the Automated Brute Forcing algorithm, first, split the request stream into parts. Second, filter for malicious IP addresses that has a number of attempts that exceeds the limit threshold. Finally, save all malicious attempts into a log file.

### SQL Ingections Algorithm

With the SQL Injections algorithm, the system is attacked with the GET and POST commands, so it filters only those two Kafka topics. First, we have to rearrange the request stream into a form of request string that consists of IP address and header parts by using flatmap and map methods.

Figure 3a shows examples of request strings that had rearranged by flatmap and map.

flatMap(\_.value().split(“\n”)).map(x => x.split(”, ”)(0), x.split(”, ”)(4) )

Figure 3a : Rearranged request string by flatmap and map methods.

The algorithm will filter the request strings that match SQLi request pattern in [16] and save it into a log file. Figure 3b shows examples of request string that match SQLi request pattern.

reduceByKey((x, y) => x + “ , “ + y).filter(x => sqli\_payload\_list.exists(y => x.\_2.contains(y)))

Figure 3b : Examples of request string match with SQLi pattern.

### Cross-Site Scripting (XSS) Algorithm

For the Cross-Site Scripting (XSS) algorithm system is attacked with the GET and POST commands, so it filters only those two Kafka topics. Similar to the SQLi algorithm, first, rearrange request string into a specific pattern. Second, filter for malicious IP addresses that has request pattern match with XSS payload pattern in [17]. Finally, save all malicious attempts into a log file.

### RequestMaker Algorithm

The RequestMaker algorithm has been created to generate sets of requests for system testing. Consists of Normal requests, Automated Brute Forcing, HTTP flood, SQL Injection request pattern, and Cross-Site Scripting request pattern. A most important part of the request is the header, which will further classify whether it is a normal request or a malicious request. The header of a normal request in this system will consist of user ID and password. For the variety of requests, the algorithm will generate random passwords from the most popular password list in [18]. Automated Brute Forcing can be detected by a certain number of attempts in a period of time. Attacks can only be carried out with the GET command according to [5] [7]. HTTP flood attacks are similar to the Automated Brute Forcing but can be attacked through all four Kafka topics (GET, POST, PUT, and DELETE). SQL Injections can be detected by malicious request header patterns. The algorithm will randomly select a SQL Injection pattern from [16] and insert it inside the request header. Similar to SQL Injections, Cross-Site Scripting uses the pattern method as the detection method. The request header information will be randomly generated within the Cross-Site Scripting list from [17].

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22. [Dataproc  |  Google Cloud](https://cloud.google.com/dataproc/?utm_source=google&utm_medium=cpc&utm_campaign=japac-TH-all-en-dr-bkws-all-all-trial-e-dr-1009882&utm_content=text-ad-none-none-DEV_c-CRE_468768393833-ADGP_Hybrid%20%7C%20BKWS%20-%20EXA%20%7C%20Txt%20~%20Data%20Analytics%20~%20Dataproc_Cloud%20Dataproc-KWID_43700029827974465-kwd-145280351817&userloc_9074522-network_g&utm_term=KW_google%20dataproc&gclid=Cj0KCQjwsdiTBhD5ARIsAIpW8CJarsE3H6OK3D5xeTNamVuRYRBN2uRehJAyfCT_I8kSegWSKpvo5R0aAtBqEALw_wcB&gclsrc=aw.ds)
23. Vonage API

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