Smart Intrusion Detection System Comprised of Machine Learning and Deep Learning

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Abstract — In the present world, digital intruders can exploit the vulnerabilities of a network and are capable to collapse even a country. Attack in Estonia by digital intruders, attack in Iran’s nuclear plant and intrusion of spyware in smart phone depicts the efficiency of attackers. Furthermore, centralized firewall system is not enough for ensuring a secured network. Hence, in the age of big data, where availability of data is huge and computation capability of PC is also high, there machine learning and network security have become two inseparable issues.

In this thesis, KDD Cup’99 intrusion detection dataset is used. Total 3, 11,030 numbers of records with 41 features are available in the dataset. For finding the anomalies of the network four machine learning methods are used like Classification and Regression Tree (CART), Random Forest, Naïve Bayes and Multi-Layer Perception. Initially all 41 features are used to find out the accuracy. Among all the methods, Random Forest provides 98.547% accuracy in intrusion detection which is maximum, and CART shows maximum accuracy (99.086%) to find normal flow of data. Gradually selective 15 features were taken to test the accuracy and it was found that Random Forest is still efficient (accuracy 98.266%) in detecting the fault of the network. In both cases MLP found to be a stable method where accuracy regarding benign data and intrusion are always close to 95% (93.387%, 94.312% and 95.0075, 93.652% respectively).

Finally, an IDS model is proposed where Random Forest of ML method and MLP of DL method is incorporated, to handle the intrusion in a most efficient manner.

Index Terms — Intrusion Detection System, CART, Random Forest, Naïve Bayes, Back-Propagation based MLP.

I. INTRODUCTION

The Internet has become an important media of regular correspondence through online media collaboration, email, e-learning, and so forth. Additionally, little and large organizations have expanded their purchaser base by giving direct client showcasing, web shopping and inter organization correspondence utilizing essential web correspondence. With the gigantic development of computer network, the total system experiences security weaknesses which are troublesome and exorbitant to be solved by manufactures [1]. A few dangers are brought through utilization of incapable and wasteful security instruments welcoming intrusions from internet hackers [2]. In this way, it is clear that the prevention technologies set up like malware evacuation programs, antivirus projects and firewalls, neglect to give outright security since aggressors utilize fresher methods for ambushing the system just as its clients [3].

Over the years, operating system security technology has been upgraded to forestall the issues of confidentiality, integrity, and availability of a network [4]. Intrusion Detection System (IDS) is a prudent early warning system for a network. For the most part, IDS alarms the client before the system gear is imperiled when it identifies inner and outside intrusion [5]. At first, network manager executes IDS physically by observing the system through a console [6]. However, the objective of this research is to propose a system security framework actualizing the Artificial Neural Network (ANN), utilizing Back Propagation (BP) calculation. The examination further breaks down oddity discovery, in light of a few AI methods, using different training and testing datasets [7].

The remaining part of the paper is developed in the following way. Segment 2 provides a literature review regarding recent updates, Segment 3 highlights some classification algorithm utilized in the work, which is CART, Random Forest, Naïve Bayes and MLP. Experimental results and analysis, the core contribution of this paper, is discussed in Segment 4. Lastly, Segment 5 conclude the paper.

II. RELATED WORK

A lot of studies have already been carried out about various machine learning and deep learning methods and its application in different fields. Same is not yet exhaustively done in the field of information security. The gap found in the field of IDS was studied with available resources till today. The unique idea of applying the machine learning and deep learning methods in the IDS is a new theme in the contemporary research arena.

A. Study Regarding IDS

According to each of the detection approaches, IDS frameworks are separated into two classifications, which are anomaly-based detection and misuse based detection [8], [9]. Misuse-based IDS can recognize known assaults effectively yet neglects to discover new assaults which fail to embody the rules in the database [10]. In this manner, a database must be persistently refreshed to store the signature of each assault that is known. This IDS type is clearly incapable to identify new attacks except it is trained [11]. Anomaly based IDS can

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assemble a typical conduct model and recognizes any significant deviations from the model similar to an interruption. This IDS type can identify new assaults or obscure one. However, it includes a high pace of false alarms [12], [13].

B. Study Regarding Dataset

The most significant challenge in assault identification framework is whether to produce genuine system traffic or to utilize the accessible benchmark datasets. There is criticism about the use of datasets acquired from genuine system traffic as it makes greater uncertainty and there is no such methodology that obviously discloses how to precisely separate between ordinary system traffic and attack traffic. This is the explanation behind utilizing the benchmark datasets for executing different attack discovery framework of this paper. The available attack datasets [14]-[17] are DARPA 1998, KDD Cup99, NSL KDD, UNSW NB15, etc. The DARPA 1998, KDD Cup99, and NSL KDD consists of 42 attributes including the class label. The UNSW NB15 dataset consists of 48 attributes including the class label.

C. Review Regarding Detection

Multiple detection methods have been carried out in various literatures. It includes traditional detection, ML-based and DL Neural-network based detection. In few research hybrid method is also used. Various detection techniques are analyzed in the following discussion.

D. Traditional Detection

A sandbox, in computer security, is a security component wherein a different, confined condition is made and in which several functions are restricted [18]. A sandbox is regularly utilized when untested code or entrusted programs from outsider sources are being utilized. Sandbox also has few constrain. Some sandbox apparatuses just deal with explicit sorts of PDF assaults like MD Scan for Java Script, [19] Nozzle for heap spraying [20], or it only records dynamic behavior of a system and still requires manual analysis to detect as in the case of CW Sandbox [21].

Huainbin Wang, Haiyun Zhou, Chundong Wang has discussed about VM-based different IDSs [22]. They have recommended to deploy VM-based numerous IDSs in each layer to observe specific virtual component. Additionally, they have also proposed the cloud alliance view, by the communication agents exchanging shared cautions commonly to withstand Denial of Service (DoS) and Distributed Denial-of-Service (DDoS). On this premise, they have accomplished an identity authentication of the communication agents, to improve the unwavering quality of the alarms. Through the evaluation of simulation results, the proposed device framework had a benefit for observing VMs on the detection rate.

E. Machine Learning (ML) and Deep Learning (DL) Based Detection

Machine learning algorithm learns from data [23]. Tom Mitchell precisely defines it as a computer program which learns from experience in respect to task and final outcome is the performance [24].

Vipin Kumar [25] used k mean clustering approach on NSLKDD dataset to perceive the accuracy for intrusion detection. Shilpaet AI [26] used fundamental element evaluation on NSLKDD dataset for feature selection and dimension pruning approach for evaluation on anomaly detection. In general, network intrusion detection has been broadly improved by applying data mining and machine learning technique, which has largely utilized individual conduct patterns from the community site visitors’ data.

Support Vector Machine (SVM) is used, as a method in a study, to evaluate IDS [27]. Among various approaches of IDS, SVM acts as a classifier with false alarm and detection rate as a measure of performance. Authors in a study [28] used Markov Chain implementation as classifier and Apriori algorithm to remove isolated data from the database and also used to judge the performance of NIDS. K-Means, an unsupervised algorithm, is used for classification, defines an unlabeled class to which the clustering is performed.

III. PRELIMINARIES

This section provides a brief background about network intrusion, and the four intelligent algorithm used in this study.

A. Concept of Network Intrusion

Modern technology has broken the border of digital intrusion and also digital threat. Attack in Estonia, Iran’s nuclear power plant, digital espionage, financial damage-all of these are the newest threat of modern internet technology. Digital intrusion is the first step and the most common type of attack or threat [29]. Then onward malwares are injected or further important arsenals are used. Thereby, if intrusions are monitored and checked then first line defense can possibly be achieved.

B. Concept of Network Attack

Analyzing the Fig. 1 it is clearly understood that first three steps of network attack cycle are related to intrusion. Therefore, it plays a vital role in overall attack cycle.

C. Overview Regarding Algorithm

There are many types of algorithms practiced in machine learning. But four suitable methods are utilized for performance analysis.
D. Classification and Regression Tree

Leo Breman introduced the term CART. CART refers to Decision Tree algorithm. It is used for classification or regression predictive modeling problems. Classically, this algorithm is mentioned as “decision trees”. However, they are also mentioned by the more modern term CART, on some platforms like R [30].

If Height > 175 cm, Then Male.
If Height <= 175 cm AND Weight > 75 kg, Then Male.
If Height <= 175 cm AND Weight <= 75 kg, Then Female.

Make Predictions with CART Models.

E. Random Forest

Random forest consists of a large number of individual decision trees. It operates as an ensemble. Each individual tree splits out a class prediction. The class with the most votes become model’s prediction (see figure below) [31].

IV. EXPERIMENTAL RESULTS AND ANALYSIS

This section discusses the performance of the proposed IDS model which is furthermore analyzed with two experiments. In case of MLP, all the features are supplied as input to the neural network and then are trained using back-propagation. Then the accuracy is calculated from the test data. But in case of Random Forest, CART, and Naive Bayes, necessary parameters are utilized. However, in the second experiment, only the most important features are extracted, and then supplied as input along with the training dataset. Finally, the results obtained are presented in tabular as well as graphical form.

A. Application of ML Methods with Generalized Features

In the first experiment four methods are applied to find out accuracy in both normal flow of data and also for intrusion. Among all the ML Method, CART and MLP has provided a better accuracy. Whereas Random Forest has provided a greater intrusion detection which is 98.547%. In Fig. 5 graphical presentation has been displayed the same.

| TABLE I: TEST ACCURACY FOR NORMAL FLOW OF DATA AND INTRUSION DETECTION USING 41 FEATURES |
|-----------------------------------------------|---------------|-------|
| Type of Algorithm | Type of Data | Accuracy |
| Random Forest      | Normal        | 85.387 |
|                    | Intrusion     | 98.547 |
| CART               | Normal        | 99.086 |
|                    | Intrusion     | 96.51  |
| Naive Bayes        | Normal        | 85.606 |
|                    | Intrusion     | 93.265 |
| MLP                | Normal        | 93.387 |
|                    | Intrusion     | 94.312 |
B. Application of ML and DL Methods with Selective Features

Repeatedly in the second experiment, four methods are applied to find out accuracy in both normal flow of data and also for intrusion. But in this case selective features are applied in four different ML Methods like Random Forest, CART, Naive Bayes, & MLP. Here, CART and Naive Bayes has provided a better accuracy although Random Forest has also provided a better intrusion detection like previous which is 98.266%. Performance of MLP has also been displayed a significant improvement. In the Fig. 6 graphical presentation has also displayed the overall performance.

TABLE II: TEST ACCURACY FOR NORMAL FLOW OF DATA AND INTRUSION DETECTION USING SELECTIVE 15 FEATURES

| Type of Algorithm | Type of Data | Accuracy  |
|-------------------|--------------|-----------|
| Random Forest     | Normal       | 90.903    |
|                   | Intrusion    | 98.266    |
|                   | Normal       | 98.246    |
|                   | Intrusion    | 93.167    |
|                   | Normal       | 98.331    |
|                   | Intrusion    | 93.458    |
|                   | Normal       | 95.007    |
|                   | Intrusion    | 93.652    |
| CART              | Normal       | 99.086    |
|                   | Intrusion    | 96.51     |
| Naive Bayes       | Normal       | 85.606    |
|                   | Intrusion    | 93.265    |
| MLP               | Normal       | 93.387    |
|                   | Intrusion    | 94.312    |
|                   | Normal       | 95.007    |
|                   | Intrusion    | 93.652    |

C. Analytical Review

Experimental results in both cases have displayed reasonably good performance. Use of selective features and elimination of few less important parameters have also improved the overall performance. After analyzing overall results, Classification and Regression Tree is found to be a stable and better method keeping in mind that Random Forest provided the best intrusion detection in both cases.

TABLE III: COMPARISON OF ACCURACY AMONG ML AND DL METHODS USING GENERIC AND SELECTIVE FEATURES

| Type of Algorithm | Type of Data | Accuracy Generic Features | Accuracy Selective Features |
|-------------------|--------------|---------------------------|-----------------------------|
| Random Forest     | Normal       | 85.387                    | 90.903                      |
|                   | Intrusion    | 98.547                    | 98.266                      |
| CART              | Normal       | 99.086                    | 98.246                      |
|                   | Intrusion    | 96.51                     | 93.167                      |
| Naive Bayes       | Normal       | 85.606                    | 98.331                      |
|                   | Intrusion    | 93.265                    | 93.458                      |
| MLP               | Normal       | 93.387                    | 95.007                      |
|                   | Intrusion    | 94.312                    | 93.652                      |

D. Proposed IDS Model

A model consisting ML and DL method is proposed in Fig. 8. Here MLP with Back Propagation algorithm is used and Random Forest is taken as ML method. The selected methods are used considering the performance in accuracy.
V. CONCLUSION

Sovereignty of a country is assured by ensuring the border security. But at the age of twenty first century border security is redundant where digital security is not guaranteed as digital world has got no border. However, living with modern technology is an important arsenal to ensure proper digital security. In this thesis, digital security vulnerabilities are discussed at the first place and subsequently it is manifested that the digital security technologies like malware removal programs, antivirus programs and firewalls, lack success to provide absolute protection. Attackers always employ updated techniques to assault the network, as well as its users. Wherefore, latest DL and ML methods are explored and finally necessary training and tests are carried out to measure the accuracy of the various DL and ML methods. MLP, one of the deep learning method along with various ML methods like Random Forest, CART, Naïve Bayes is also analyzed. The ML and DL methods are found to be very prudent in network security. Eventually, an IDS model is proposed where MLP and Random Forest is put into action.

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