Immune-Genetic Algorithm (IGA) with Local Search For Intrusion Detection System in Computer Network

Hamizan Suhaimi, Saiful Izwan Suliman, and Ismail Musirin

Abstract—The Internet provides almost unlimited connectivity to the online world that is widely used in our daily lives nowadays. As for borderless connections, inventors have to face great challenges in providing the greatest quality of service specifically in terms of security. Even with existing security measures such as firewalls, Intrusion Detection System (IDS) and antivirus to protect the network, the network is still vulnerable and its resources can be compromised by third parties. This problem highlights the need to address network intrusion problems efficiently. By formulating a specific algorithm for this problem, the purpose of this study is to examine the performance of improvised Genetic Algorithms for network intrusion problems. Based on the 1999 KDD Cup data set with various disruptions simulated from the military network, this research was conducted based on this standard dataset. The performance in terms of average intrusion detection rate and false alarm rate of the proposed method and other available techniques were analyzed to evaluate and determine the best performance. The combination of Genetic Algorithms, Immune Algorithm and local search has produced good detection with accuracy rate of 98.91% and has the potential to be further investigated for other research areas.

Index Terms— Intrusion Detection System, Genetic Algorithm, computer network systems.

I. INTRODUCTION

In this era of borderless world, most companies that provide communication services compete with each other to provide the best services in terms of data transfer rates including extensive internet coverage [1]. The need of Intrusion Detection System (IDS) is very crucial with extensive internet coverage [1]. The best services in terms of data transfer rates is designed to detect any intrusion by monitoring network traffic and detect any suspicious activity such as illegal network access and malicious attacks [4]. Previous research has shown that they do not consistently obtain detection rates higher than 90% [2]. This can be due to the selection of data for training and testing process which was done based on probability. In addition, the main source of the raw data contains some errors that can increase false negative rate. This study was conducted to evaluate the performance of different methods used in tackling such problem. It focuses on the effect of mutation and data selection probabilities on detection rate in each iteration. The proposed method utilized in this study is Genetic Algorithm combined with a crucial step in Artificial Immune System (AIS) to improve the generated candidature solutions. This algorithm is further enhanced with the utilization of taboo tenure extracted from Tabu Search algorithm, hence the name of the proposed method.

II. PAST RESEARCH

There are many researchers who have proposed GA with additional method(s) to make improvements to the proposed method. An improvement method for GA has been proposed by a group of researchers from the University of Mumbai. P. U. Kadam and P. P. Jadhav [7]. In their research, GA was utilized with all forty-one features for the chromosomes. Using a newly developed solution, it has been evaluated using a fitness function to calculate the decency of each chromosome based on the desired solution.

B. Chakrabarty et. al has conducted studies on IDS based on anomalies using GA hybrids and K-Centroid Clustering [2]. In this study, two datasets which are KDD’99 Cup and NSLKDD were used to conduct experiments for IDS.NSLKDD data set has been identified to be able to solve problems in the KDD’99 data set. For this research, GA with K-Centroid Clustering was performed on the specific clusters. Clusters were created to differentiate groups for specific disruptive and normal data. During clustering, different clusters were also created for

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similar connection types. S. Sharma et. al has made a review of GA and Fuzzy Logic approaches for IDS [8]. Since KDD’99 dataset has some redundancy issues, NSLKDD was used as the main dataset. As a result of this study, the fuzzy-GA hybrid has performed better than the single GA technique.

GA with new features selection has been proposed with SVM classification to improve detection accuracy [9]. Data collectors and pre-processing modules have been proposed for data pre-processing, extraction and classification of data. This pre-processing technique is used for data reduction from the KDD99 data set where only the most relevant features are selected and used for detection. According to [10], GA is proposed together with SVM to overcome the problem of difficulty in identifying new data and the need for large data sets to do so. The proposed GA with SVM has resulted in a better detection rate with a low false positive rate compared to the Advanced Feature Selection Algorithm (FFSA) and Linear Correlation Feature Selection (LCFS).

A study for IDS using hybrid GA-SVM and selection of new features has been proposed by H. Gharaee and Hosseinvand [11]. In their research, a new fitness function has been introduced with the Least Squares Support Vector Machine (LSSVM). Using the KDD’99 and UNSW-NB15 Cup data sets, the proposed method has involved three main steps: character selection based on GA, training and classification. As a first step of detection, LSSVM is trained in the training division. Then, traffic data is classified into normal or anomalous classes. In this paper, three parameters have been introduced for the new fitness function which are Positive Rate (FPR), True Positive Rate (TPR) and the number of features selected to calculate each subset of features. In producing results, MMIFS model using KDD'99 Cup has been applied into LSSVM model to compare with other methods such as GA-Fuzzy SVM, MMIFS, SVM and C4.5.

Feature selection of GA with multiclass SVM classifier was proposed by Ganapathy et al [12]. In their research, only 10 features from 40 features were selected for the new dataset. The proposed technique has managed to get better accuracy compared to other techniques. In [13], SVM classifier was proposed for GA to select the most important features and useless elements in recognizing attacks. Instead of using KDD Cup 99, NSL-KDD is used as the main dataset using only 28 features while the rest features have been omitted. In 2016, A. S Desai and D. P Gaikwad proposed the Fuzzy-Genetic Algorithm hybrid method to identify internal and external attacks of network systems [14]. Signature matching algorithms can be used to identify attacks from the internal system while FGA was proposed to detect external attacks in the network. In the internal systems, SQL injection which consists of static and dynamic injection detection became the main focus. In static parts, query are classified as malicious attack if the comparison is match with the stored signature, otherwise it is normal. In dynamic detection, query are considered as malicious if it exceeds the threshold value when using calculation of similarity index from the comparison.

Studies on the combination of 2 techniques have been done over the past few years. The combination of Artificial Neural Networks (ANN) and GA for IDS was done by A. Dastanpour et al. to study the effectiveness of both techniques [15]. A comparison was also made between the proposed technique with the GA-SVM model to evaluate and observe the performance of both models. Both models function as classifiers for GA, used for the process of recognition and data classification into groups according to attack and normal traffic. Despite only using a low number of features, GA-ANN (18 features) managed to produce good performance and more effective than GA-SVM which uses 24 features. Based on the study by the same researcher [16], GA technique generates the first feature at random while the remaining features were formed by GA and ANN classification. In this research, a comparison of achievements for the proposed GA-ANN was conducted with other techniques such as Modified Mutual Information-based Feature Selection (MMIFS), Forward Feature Selection Algorithm (FFSA) and Linear Correlation Feature Selection (LCFS). The results of the study found that GA-ANN can achieve the highest detection rate using only 18 features while other techniques require at least 21, 24 and 34 features respectively to get the same result. Feature selection for proposed GA and ANN classification acts as the main cause to produce good results even if the data features are reduced to a minimum value.

According to a study from J. Kaliappan et al. [17], ANN can be used to derive meaning, analyze and process information from complex noisy data. Supervised learning is the process of ANN being able to learn a task with random responses. Reactions can weaken the connection when the wrong decision is made or strengthen the connection for the right decision. Studies using K-Nearest Neighbor (KNN) and GA for IDS were also conducted by researchers to improve computer network security. According to Y. Canbay and S. Sagiroglu [18], KNN is generally used by test samples ’neighbors voting to determine the class labels from the test set. For hybrid GA, KNN is used to calculate the distance and to classify test samples by creating neighborhood diversity using its operators. After scanning all training data, KNN will calculate the distance between each test sample and training sample. KNN has several limitations such as high calculation complexity and training set dependency where it needs all training datasets to create a model [19]. Eventhough, KNN is an efficient algorithm and easy to implement [20].

III. THE PROPOSED METHOD

The proposed Immune-Genetic Algorithm (IGA) with local search involved 3 main phases which are data division, training and testing phase. The main steps involved in this IGA system are discussed in the following sections:

A. Data division

The dataset utilized in this study was taken from KDD-99 The Fifth International Conference on Knowledge Discovery and Data Mining [21]. A total of 251,411 raw connection data were investigated in this study. The first step taken before the implementation of the proposed algorithm is the process of separating the main data set into two groups. During this phase, raw data were divided according to the standard formulations of 10% and 90% for the respective testing and training process. Normal and intrusion connections were chosen at random based on the probabilities value for the algorithm. Preliminary investigations were performed with probabilities of 0.2, 0.3 and
0.5 for the data separation process using IGA method. This process is important to determine the optimal value that will result in the best average of intrusion detection. In this process, each probability value was executed twenty times and the results were recorded and analyzed. Probability value of 0.3 was finally chosen to be applied in the IGA-Local Search and other method (GA and AIS) as it produces the best average of detection rate.

B. Training process

The training process for the proposed IGA with local search is shown in Error! Reference source not found.. The initial population was randomly generated and then trained using Immune-Genetic Algorithm (IGA) along with local search improvement methods. This training process involves processes such as data selection, crossover (recombination), mutation, and data regeneration. In the process of chromosome selection, only the top 20 individuals with the highest fitness value were selected to be cloned twice and subsequently crossover process occurs. In this implementation, crossover rate was used to perform chromosome regrouping. Based on the standard crossover process, the probability is used to determine how often a crossover will be performed in training process. In the proposed algorithm, a child will be produced each time the crossover rate is met. This chromosome is then mutated based on the mutation probability set at 0.15 as it produces the best average detection compared to other probabilities tested. Fitness value for the mutated chromosome is calculated. The new population is then sorted from the best to worst.

Step 1: Save 100 population of chromosomes from training process into new file.
Step 2: Detect intrusion using 100 trained chromosomes and chromosomes of testing data.
Step 3: Save the total number of unrecognized attacks into “Unrecognized Testing Data.txt”.
Step 4: Display the total of successful detection and false alarm value.

A new population of chromosomes is then produced from a combination of the 30 best chromosomes from the initial population, 30 mutated chromosomes and 40 newly produced chromosomes. The fitness value of the chromosomes will be calculated, and the chromosomes will undergo the same training process for the next 90 iterations.

After the 90th iteration, a tabu list is constructed. This list consists of twenty chromosomes generated for the initial solution. In the last ten iterations, each new chromosome will be compared with the chromosomes stored in the tabu list. If it is of worst quality, a new chromosome will be regenerated. This process is repeated until all the chromosomes produced in the population have better fitness value than the chromosomes stored in the tabu list. This process is performed based on the concept of tabu search, which is considered as one of the effective local search method. It is done with the hope of generating good-quality solutions for this intrusion detection problem.

C. Testing process

Figure 2 above shows the testing process where the final population from the training process was used to identify whether data in testing file is an attack or not. Testing data which is successfully recognized is considered as success detection either it is correctly predicted as normal/attack connection or vice versa. During the testing phase, a total of 24920 connections were investigated. These connections refer to a set of internet connections with specific attributes which were extracted from the main dataset (KDD Cup’99).

In order to evaluate the performance of the proposed method during the testing phase, 4 categories of detection were identified which are true positive, false negative, true negative and false positive [5][6]. All categories are calculated using the equations below:

\[
\text{True Positive Rate (TPR)} = \frac{TP}{TP+FN} \times 100\% \quad (1)
\]

\[
\text{False Negative Rate (FNR)} = \frac{FN}{TP+FN} \times 100\% \quad (2)
\]

\[
\text{True Negative Rate (TNR)} = \frac{TN}{TN+FP} \times 100\% \quad (3)
\]

\[
\text{False Positive Rate (FPR)} = \frac{FP}{TN+FP} \times 100\% \quad (4)
\]
\[
\text{Success Detection Rate} = \frac{TP+TN}{\text{total testing data}} \times 100\% 
\]

Equation (5) identifies the true positive rate which is calculated based on the number of testing data that is correctly predicted as an attack connection. The false negative rate which is calculated using equation (5) identifies the number of attack connection (from the testing data) which are predicted as normal connection. Equation (5) will calculate the true negative rate (TNR) based on number of normal connection that is correctly predicted whereas false positive rate (FPR) identifies the number of normal connection that is predicted as attack connection. The effectiveness of the proposed algorithm can be evaluated by using equation (5) based on the number the testing data that is correctly predicted.

IV. RESULTS

The proposed IGA with local search has been implemented on IDS using data selection and mutation probabilities of 0.3 and 0.15 probability respectively. The values were set based on the test of the effectiveness of the probability value of IGA on the IDS simulation. Both probabilities produced high average attack detection rate compared to other probability values. The result can be seen in Figure 3.

![Figure 3: Results for 3 different selection probabilities on IDS in 50 iterations](image1)

Three probabilities of initial data selection were investigated to evaluate their performance on this IDS and the results are shown in Figure 3. Based on the investigation, probability of 0.3 produces the best detection rate among the three with 93.504% accuracy of detection. This is followed by 0.5 and 0.2 probabilities with 93.276% and 88.614% accuracy respectively.

This experiment were conducted by using 0.15 probability of mutation as it produces the best result from the previous investigations. The training process was conducted in 50 iterations before the testing phase took place.

Figure 4 shows the results for the same problem setting as utilized in Figure 3 except that the training process was conducted in 100 iterations. The same pattern of results can be observed as presented in Figure 3. Probability of initial data selection of 0.3 was chosen to be utilized in our proposed algorithm and the results is presented in Figure 5.

![Figure 4: Results for 3 different selection probabilities on IDS in 100 iterations](image2)

Based on the results shown in Figure 3 and Figure 4, probability of initial data selection of 0.3 was chosen to be utilized in our proposed algorithm and the results is presented in Figure 5.

![Figure 5: Total average of intrusion detection rate for each attack based on 0.3 probabilities of data selection](image3)
In order to evaluate the performance of the proposed IGA-LS, comparative studies with other methods were conducted on the same dataset. A standard Genetic Algorithm (GA), Artificial Immune System (AIS) and Immune-Gene Genetic Algorithm (IGA) were chosen for this purpose. The details comparison are shown in Error! Reference source not found.. Within 20 series of run, IGA-LS produces the highest attack detection rates for all five attacks investigated compared to other 3 methods. Immune-GA is the second best method for GuessPassword and Neptune attack with an average of 90.721% and 87.84% accuracy rate respectively. AIS algorithm is superior than standard GA and Immune-GA for Mailbomb and Smurf attack. Meanwhile, standard GA is better in detecting SnmpGetAttack with 97.125% detection average rate. In overall, IGA-LS produces 98.809% positive detection rate for all five attacks. This is followed by Immune-GA (94.69%), standard GA (93.95%) and AIS (93.62%). These results are illustrated in Figure 6. From the results shown in Table 1, GuessPassword is the most difficult attack to be detected. Immune-GA with local search is the best performer with only 65% of the testing data accurately identified. This is because of the properties for the GuessPassword attacks vary distinctly one another. Hence, making it difficult for the algorithms to correctly identify the patterns.

The dataset utilized in this study consists of two types of connection data, which are attack connection and normal connection. The results obtained were further analyzed based on these two categories.

As discussed in Section II, four detection categories were investigated which are True Positive Rate (TPR), False Negative Rate (FNR), True Negative Rate (TNR), and False Positive Rate (FPR). The values for these four rates were calculated and shown in for all methods. For attack connection detection in testing phase, 23920 testing data were utilized.

The proposed Immune-Gene Genetic Algorithm with local search (IGA-LS) method produces the highest TPR value of 99.639% as compared to other three methods. It shows that IGA-LS has managed to identify the most number of attack connection. This is also reflected in False Negative Rate with IGA-LS produces the lowest value which indicates the least number of attack connection wrongly detected. However, this is not the case for normal connection detection. The proposed IGA-LS is the worst-performing method with the lowest True Negative Rate (5.7%). AIS is the best for this criteria with 30.5% successful detection rate. When both attack and normal connections are considered, IGA-LS produces the best result with 95.41% of successful detection rate. This is followed by IGA with 95.34%. Even though the difference is quite small which is 0.07%, it shows that local search has managed to slightly increase the detection rate. However, this small value represents more than 1700 testing data which is very crucial in making sure a computer network is secured from any illegal intrusion.

### Table 2

<table>
<thead>
<tr>
<th>Types of Detection Rate</th>
<th>IGA (%)</th>
<th>IGA-LS (%)</th>
<th>Standard GA (%)</th>
<th>AIS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>False Negative Rate (FNR)</td>
<td>0.81</td>
<td>0.361</td>
<td>0.726</td>
</tr>
<tr>
<td>Condition Negative (Normal)</td>
<td>True Negative Rate (TNR)</td>
<td>19.30</td>
<td>5.70</td>
<td>16.40</td>
</tr>
<tr>
<td></td>
<td>False Positive Rate (FPR)</td>
<td>80.70</td>
<td>94.30</td>
<td>83.60</td>
</tr>
<tr>
<td>Total Detection</td>
<td>Success Detection Rate</td>
<td>95.34</td>
<td>95.41</td>
<td>94.51</td>
</tr>
</tbody>
</table>
V. CONCLUSION

There are many aspects that can influence the effectiveness of a network intrusion detection system. For a population based metaheuristic like Genetic Algorithm, the initial value of all parameters involved is very crucial as it will determine the quality of the produced solutions. In this study, the probability of the initial data selection was investigated. This probability value will determine the type of connections that will be allocated in both training and testing dataset. This allocation process can be a decisive factor to make sure the population of antibodies (a set of candidate solutions) is good enough to be used to detect any occurrence of network intrusion. The combination of optimal probability values for initial data selection and mutation on the proposed IGA-LS helps in improving the average intrusion detection rate as well as True Positive Rate.

The utilization of a local search method on the Immune-Genetic Algorithm (IGA) is aimed to improve the Positive Detection Rate. This was investigated in this study as the framework for tabu search method was modelled and implemented in solving this intrusion detection issue. The presented results have proven that the proposed local search has the capability to further improve the detection rate, thus showing its effectiveness in helping IGA to explore the solution neighbourhood for better outcomes.

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S. Hamizan is a máster student by research at the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), Malaysia. He graduated in Diploma of Electrical Engineering (Electronic) in 2014 and obtained 1st class bachelor degree (Honor) in Electronic Engineering from UiTM in 2018. His research interest is mainly in the area of computer network especially genetic algorithm and intrusion detection system.

Saiful I. Suliman is a senior lecturer at the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), Malaysia. He obtained 1st class degree in Artificial Intelligence in 2002 and Master of Science (Electrical Engineering) from UiTM in 2006. His Phd was awarded by The University of Nottingham, UK in 2015. His research interest is mainly in the area of artificial intelligence, optimization and pattern recognition algorithm, metaheuristic approach, frequency bandwidth spectrum and power system operations. He has published papers in many international conferences as well as reputable journals. He is a certified Professional Technologist and Chartered Engineer (CEng) with IET, UK. He is currently
the head of Innovation Unit, Research Management Centre (RMC) at UiTM.

Ismail Musirin received the bachelor’s degree (Hons.) in electrical engineering from Universiti Teknologi Malaysia, in 1990, the M.Sc. degree in pulsed power technology from the University of Strathclyde, U.K., in 1992, the Ph.D. degree in electrical engineering from Universiti Teknologi MARA (UiTM), Malaysia, in 2005, and the Diploma degree in electrical power engineering from Universiti Teknologi Malaysia (UTM), in 1987. He is currently a Professor of power system with the Faculty of Electrical Engineering. He has authored and coauthored two books, more than 300 articles in international journal and indexed conferences. His research interests include artificial intelligence, optimization techniques, power system analysis, renewable energy, distributed generation, and power system stability. He is a Senior Member of the International Association of Computer Science and Information Technology (IACSIT), and a member of the Artificial Immune System Society (ARTIST) and of the International Association of Engineers (IAENG). He is also an International Journal Reviewer of the IEEE Transactions, Science (Elsevier), WSEAS, John Wiley, IET, and some other publishers.