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Generative Adversarial Network Approach to Game Based Intrusion Detection System

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ABSTRACT

This ongoing research work presents a new approach to Intrusion Detection System called Generative Adversarial Network Approach to Intrusion Detection System. The new concepts of ubiquitous computing and high capacity data transfer have turned the internet into today's commerce. An intrusion detection system (IDS) comprises of hardware and software elements that work together to find unexpected events that may indicate an attack will happen, is happening, or has happened. This research work want to leverage on the power of Machine Learning Algorithms to develop an intrusion detection system using Generative Adversarial Network and evaluation of the model based on results obtained from case study of intrusion detection in some selected networks. It is expected that the result will determine attackers' behavioral pattern on a network and also provide an enhanced intrusion detection model that prevents attackers' actions to be carried out on a network.

Keywords: Information Security, Generative Adversarial Network, Intrusion Detection System, Deep Learning

1. BACKGROUND TO THE STUDY

The new concepts of ubiquitous computing and high capacity data transfer have turned the Internet into today's main area for information interchange and electronic commerce. As network systems become more and more complex and interconnected, their security plays an increasingly important role mainly because they are supporting critical applications. Attacks against computer networks used by modern society and economics for communication and finance can therefore threaten the economical and physical well-being of people and organizations. The security of an Information Communication Technology (ICT) system and its components is hence a research area of ever increasing interest. To this effect, Information security has become one of the major concerns since critical decisions are made based on information stored and analysed by software systems. As a result of this, the need for effective techniques to protect software systems from malicious attacks has increased the level of significance of the software security field to meet industry needs. Attacks can range from viruses/worms, Internet browser exploits through the identity theft to more severe threats such as cyber-attacks and cyber-terrorism. Wired and wireless infrastructure-based networks are designed to secure networks by using firewalls and encryption techniques but they still suffer from different types of intrusions. As there is increasing reliance on computer and network systems to support critical operations in defense, banking, telecommunication, transportation, school, insurance, electric power etc., computer system and network insecurity become important threat to our society with severe potential consequences. Cyber–attack and cyber insecurity are launched through a series of computer actions to compromise the security (such as service availability, integrity, and confidentiality) of computer and network systems.

Network Attack can be defined as any attempt to destroy, disable, steal or gain unauthorized access to a network asset.
Some of Classes of Network Attacks on Computer Network System

i. Side Channel Attacks: The attacks are based on information that is gained from the physical implementation of a cryptosystem rather than brute force or theoretical weakness in the algorithms. Timing analysis, acoustic analysis and power consumption analysis are some instances that belong to this class.
ii. Cryptographic/ Protocol Attack: This is a method for circumventing the security of a cryptographic system by finding a weakness in a code, cipher, cryptographic protocol or key management scheme.
iii. Implementation Attack: This attack refers to a type of cryptanalysis attack that does not target cryptographic algorithms and protocols directly. This attack aims at implementation of cryptographic systems (the smartcards and USB tokens) to gain knowledge about secret information. These attacks refer only to certain implementations of the SSH- Server or the SSH-Client. Since the number of SSH implementation is usually high, the attacks appear very frequently.
iv. Denial of service attacks: Denial of service (DoS) attacks against Network system providers may leave tenants without access to their accounts. This can occur by sending a flood of traffic to overwhelm websites to make them inaccessible to legitimate users. When a DoS attack is conducted using a botnet (a network of compromised machines), this is referred to as a distributed denial of service attack, or DDoS. DoS attacks aimed at individual accounts may be accomplished by changing the tenant's password or maliciously continuing to enter the incorrect password so that the account becomes locked.
v. Man-in-the-middle attacks: Here, the attacker intercepts traffic between a website and a Browser [21]. This occurs when the browser believes that the attacker is the legitimate website and the website authenticates the attacker as the browser. The attacker can then read and alter the data being transmitted, including account passwords that may be used to login to a network system.

vi. Network/Packet sniffing: Network or packet sniffing involves the interception and monitoring of network traffic [11]. Data that are being transmitted across a network, such as passwords, can therefore be captured and read if not adequately encrypted.

1.1 Intrusion Detection System (IDS)

An intrusion detection system (IDS) comprises of hardware and software elements that work together to find unexpected events that may indicate an attack will happen, is happening, or has happened [3]. An intrusion detection system (IDS) examines system or network activity to find possible intrusions or attacks. Therefore, an Intrusion detection system (IDS) is a security system that monitors computer systems and network traffics and thereafter analyzes such traffic for possible attacks originating from outside or within the organization. Intrusion detection systems can be categorized into network-based intrusion detection system (NIDS), host-based intrusion detection system (HIDS) and stack-based intrusion detection system (SIDS).

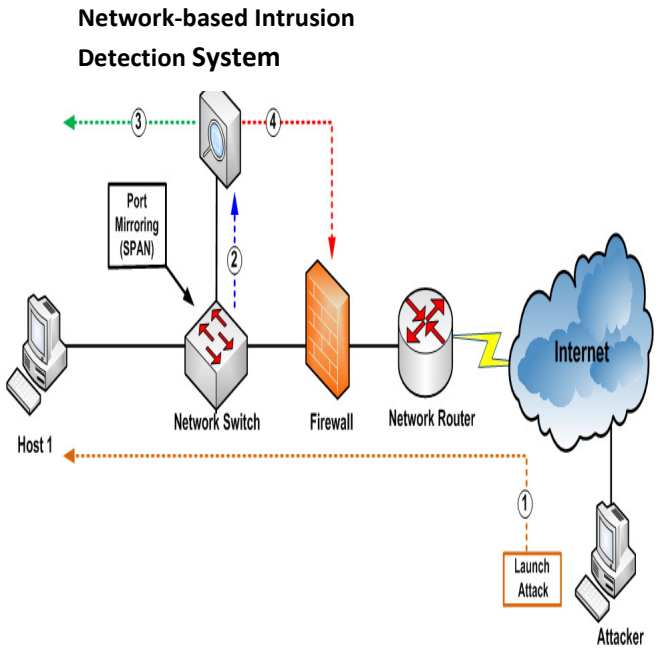

Fig. 1.: Network-Based Intrusion Detection System (ieee 2014 java project)

1.2 Game Theory

Game theory is a branch of applied mathematics that uses models to study interactions with formalized incentive structures ("games"). Game theory usually considers a multiplayer decision problem where multiple players; the attackers (malicious users) and the defenders (network/system administrator) [2, 5, 22] with different objectives can compete and interact with each other. Game theory describes the decision scenarios of two or more players as games in which each player chooses actions to bring the best possible payoffs for the player while anticipating the rational actions from other players [12]. Deep Learning (also known as deep structured learning or hierarchical learning) is part of a broader family of machine learning methods based on learning data representations, as opposed to task-specific algorithms. Learning can be supervised, partially supervised or unsupervised.

Deep learning is a class of machine learning algorithms that:

- use a cascade of multiple layers of nonlinear processing units (a nonlinear filter is a filter whose output is not a linear function of its input. That is, if the filter outputs signals R and S for two input signals r and s separately, but does not always output $\alpha R + \beta S$ when the input is a linear combination $\alpha r + \beta s$) for feature extraction and transformation. Each successive layer uses the output from the previous layer as input.
- learn in supervised (classification) and/or unsupervised (pattern analysis) manners.
- learn multiple levels of representations that correspond to different levels of abstraction. These levels form a hierarchy of concepts.
- use some form of gradient descent for training via backpropagation.

In [11], Generative Adversarial Networks (GANs) are a class of artificial intelligence algorithms used in unsupervised machine learning, implemented by a system of two neural networks contesting with each other in a zero-sum game framework. It consists of a generative network and a discriminative network. Due to the competition arising from the two networks, it learns to model the data distribution. The two players in a game are represented by two functions, each of which is differentiable both with respect to its inputs and with respect to its parameters. It is usually refers to zero-sum game. The Discriminator is a function D that takes x as input and uses (D) as parameters and The Generator is defined by a function G that takes z as input and uses (G) as parameters. Both players have cost functions that are defined in terms of both players' parameters.

The discriminator $J^{(D)}\left(\theta^{(D)}, \theta^{(G)}\right)$ wishes to minimize and must do so while controlling only (D) and the generator $J^{(G)}\left(\theta^{(D)}, \theta^{(G)}\right)$ wishes to minimize and must do so while controlling only (G). Each player's cost depends on the other player's parameters, but each player cannot control the other player's parameters, this scenario is most straightforward to describe as a game rather than as an optimization problem. The solution to an optimization problem is a (local) minimum, a point in parameter space where all neighbouring points have greater or equal cost. The solution to a game is a Nash equilibrium.

2. STATEMENT OF PROBLEM

Information security has become one of the major concerns since critical decisions are made based on information stored and analysed by software systems. Attacks against computer networks used by modern society and economics for communication and finance can therefore threaten the economical and physical well-being of people and organizations. Wired and wireless infrastructure-based networks are designed to secure networks by using firewalls and encryption techniques but they still suffer from different types of intrusions.

In view of the above problems, our work will looks at Generative Adversarial Networks **(**GANs**)** to resolve the problem of intrusion by hackers in a network environment.

3. OBJECTIVE

The object of the work is as follows:

i. develop a game based model for network intrusion detection using Generative Adversarial Network.
ii. implement the model formulated in (i) above.
iii. evaluation of the model based on results obtained from case study of intrusion detection in some selected networks.

4. REVIEW OF RELATED WORK

Due to the importance of Intrusion Detection System in security system, so many researches have been carried out on it in different direction.

In [12], Network Packet Sampling strategy to reduce the success chances of an intruder was proposed. The difference in the form of intrusions experienced by wired-based networks using fire-wall and encryption techniques is the key motivation for this work. In their work, they develop a network packet sampling strategy for reducing the success chances of an intruder in a wired infrastructure based networks. Their work is limited to Network Packet Sampling strategy which led to the problem of missing some intrusions due to its sampling budget constraints.

In [19], a self-adaption mechanism for network intrusion detection system which uses a game-theoretical mechanism to increase system robustness against targeted attacks on Intrusion Detection System was developed. When adaption techniques were deployed improperly, it can allow the attackers to reduce the system performance against one or more critical attacks which can lead to a potential attacked for an informed and sophisticated attackers. The research work is on the design of a self-adaptation mechanism for network intrusion detection system. The method adopted in the work was the concept of challenge insertion and used for the design which help in inject a small sample of simulated attacks into the unknown traffic and use the system response to these attacks to define the game structure and utility functions. The work is only based on a distributed agent-based Intrusion Detection System without looking into other form of Intrusion Detection System.

In [3], the basis trade-offs, analysis and decision process involved in information security and intrusion detection as well as possible application of game theoretic concepts to develop a formal decision and control framework was documented. Current IDS's rely mostly on human intervention in decision and response processes against attackers, that are often automatic and script based. Today's IDS are inefficient and delayed in responding to security breaches in the network. Due to the distributed nature of the networked system, a centralized security system poses scalability and efficiency problems. The researchers developed a security warning system with network sensors. GAMBIT game theory analysis tool was adopted and used in investigating the basic decision and analysis processes involved in the research work. The work did not develop a practical algorithms to be used and decentralization of the decision and processes were not developed and implemented.

In [23], an ad-hoc intrusion detection model based on the game theory was presented. Since mobile Ad-hoc network are kind of temporary autonomous network system which comprised of a number of wireless mobile node without control center through which the nodes of mutual cooperation network interconnection is possible, intrusion of such network is at high risk. The research work entails the designs of the response scene between the attacker and defender in the Ad-hoc network and Compare node survival and success rate of defense in two scene networks. GloMoSim platform was used to test the model developed. The experimental scene is limited to 500m*500m and experimental time is 60s which has greater effects on the security management of the network.

In [4], Game theory and intrusion detection system was documented. Intrusion detection system has long been utilized in detection and response strategy to potential attacks. However, effective policing and finding a right balance between tradeoffs has always been an issue. The work analyzed the available game theoretic approaches for intrusion detection systems. Adaptive snort were adopted and used for the analysis of the available game theoretic approaches. The work only stopped at the review stage. No specific implementation was proposed.

In [1], documentation on Intrusion detection in sensor networks and non-cooperative game approach is presented. The need to unravel the factors responsible for the insufficiency of memory and battery power of sensors which makes the security of networks very tasking. This also contributes to the unstable form of networks on the sensor. The researchers developed a game theoretic framework for defending nodes in a sensor network by formulating an attack-defence problem as a two-player, nonzero-sum, non-cooperative game between an attacker and a sensor network. Markov decision process to predict the most vulnerable sensor node, intuitive metric (node's traffic) and protect the node with the highest value of this metric was used in the framework. The most vulnerable node in a sensor network is their main concerned leaving the less vulnerable nodes unprotected thus, create another set of risk in sensor network. In [14], A game-theoretic scenario for modelling the Attacker Defender Interaction was presented. Exiting Computer Security techniques lack decision frame work required to defend against highly organized attacks. Many mathematical models such as Machine Learning, Control Theory, Data Mining etc. have been used to model and analyse the decision making problems but they all the models fail to capture the rationality and dynamic nature of players involved in security provisioning large scale network. The researchers developed a stochastic game-model that view the interaction between malicious users and network administrators a two-player zero sum game. A binary coding scheme was employed for identifying game states and game transition diagrams were generated to describe possible movements of player. A stochastic algorithm was developed to solve the game and compute the optimal strategies for the players. Their emphasis was not on how the attackers operate and their pattern on the network. Also risk computation was not done which supposed to help in analysis of the attacks and predicting attacker's behaviours on network.

5. METHODOLOGY

A detailed review of existing literature in the area of game theoretic based intrusion detection system was carried out. The review highlighted the fundamental concept of game theoretic based intrusion detection system, their strength and limitation. A typical game scenario is played over a computer network environment made up of several interconnected components (asset) and game actors. Network assets consist of firewalls, databases, file/print, application servers, routers and cryptographic devices. The game actors are network/virtual users, normal users attempting to accomplish a task, attackers who exploit vulnerabilities and defenders whose responsibility is to secure the network from malicious threats to both internal and external factor. The game model for the ongoing research work is model by considering a multiple-player zero-sum game played on a finite state space, where each player has a finite set of actions to choose from. The multiple-player stochastic game is defined as a tuple in the equation below:

$$G = (S, M, (A_i, \propto_i, U_i)_{1 \le i \le |p|}, Q) \ldots \quad (1.1)$$

where

S is a State $S = \{s_1, s_2, s_3, \ldots s_t\}_{1 \le t \le |s|}$

M is a Player $M = \{M_k\}_{k=1,2,3,\ldots n}$

A_i is an Action $\forall(p_k \in M) \exists A_i = \{a_1, a_2, \ldots a_n\}$

$\propto_i$ is a State Action $\propto_i : S \to A,\ i = 1,2,3+$

Sa is a player profile

$Sa = \{(s,a): s \in S, a = (a_i), a_i \in \alpha_i(s); 1 \le i \le |M|\}$

U_i is a Payoff $U_i : Sa \to R, i = 1,2,3\ldots$

Q is the Probability Distribution $Q: SA \to M(S)$

The research work presents the player of the game as the defender M_1 and the attacker M_2 and the action spaces of the players are the sets of possible attack moves and defense counter measures respectively. The work encapsulates each attack or defence as a single action achieving a specific goal. The finite action spaces for both the defender (M_1) and attacker (M_2) are defined as follows in equation below:

$$A_1 = M_1^a = \{a_1, a_{2n}, \dots a_n\}\dots \quad (1.2)$$
$$A_2 = M_2^a = \{a_1, a_{2n}, \dots a_n\}\dots \quad (1.3)$$

At every state of the game, players have at their disposal a finite set of actions from the nature of the configuration of the network if the actions are unique across states.

GAN Objective Function

$$\min_G \max_D V(D,G) = E_{x\sim p_{data(x)}}[\log D(x)] + E_{z\sim p_{z(z)}}\left[\log\left(1 - D(G(z))\right)\right] \quad (1.4)$$

where $p_{data(x)}$ = Data distribution usually represented by sample
PG(z) = Model distribution , where z is usually modelled as uniform or Gaussian of a random variable.

The outcome of the model will be assembled to form another set of data distribution which will be passed into a Generative Adversarial Networks (GANs) to classify a data onto the data distribution using minmax optimization as an attacker and non-attacker. A noise will be introduced to a random sample and the generator network will produce a fake sample of the model distribution. The classier will be trained as two minibatches of data; one coming from the dataset, where the label is 1 for all examples, and one coming from the generator.

5.1 Algorithm for training GANs

for number of training iteration do
for k steps do
sample minibatch of m noise samples $\{z^{(1)}, \dots\dots\dots, z^{(m)}\}$ from noise prior $p_g(z)$
sample minibatch of m example $\{x^{(1)}, \dots\dots\dots, x^{(m)}\}$ from data generating distribution $p_{data(x)}$
Update the discriminator by ascending its stochastic gradient:

$$\nabla_{\theta_d}\frac{1}{m}\sum_{i=1}^{m}\left[\log D(x)^{(i)} + \log\left(1 - D\left(G(z^{(i)})\right)\right)\right]$$

end for
sample minibatch of m noise samples $\{z^{(1)}, \dots\dots\dots, z^{(m)}\}$ from noise prior $p_g(z)$
Update the generator by descending its stochastic gradient:

$$\nabla_{\theta_d}\frac{1}{m}\sum_{i=1}^{m}\left[\log D(x)^{(i)} + \log\left(1 - D\left(G(z^{(i)})\right)\right)\right]$$

end for

5.2 Attacker's Behaviors Computation on Network

i. Identifying the game element

From the stochastic model, we will pick all states where the system is vulnerable to attacks. Each of the state can be viewed as game element in multiple-player, Zero-Sum stochastic game.

ii. Construct the action set

This consists of all possible attacks action. For all transitions out of the game elements which represent intrusions, there will be corresponding attacker's action.

$$A_i = \{a_1, a_2, a_3 \ldots\ldots\ldots a_n, \emptyset\} \ldots \quad (1.4)$$

where Ø is inaction

iii. Assign Reward and Cost

In the game element, we assign two values to each attack action r_i= a|undetected and r_i= a|detected.

iv. Compute transition probabilities between game states.

v. Solve the game model using matrices.

vi. The output of the game model will be feed into Generative Adversarial Network an attack or not attack

The ongoing research work will make use of Generative Adversarial Network identify attackers on the network and prevent the attacker(s) from carrying-out its intended action. Generative Adversarial Networks (GANs) are a class of artificial intelligence algorithms used in unsupervised machine learning, implemented by a system of two neural networks contesting with each other in a zero-sum game framework. It consists of a generative network and a discriminative network. Due to the competition arising from the two networks, it learns to model the data distribution [11].

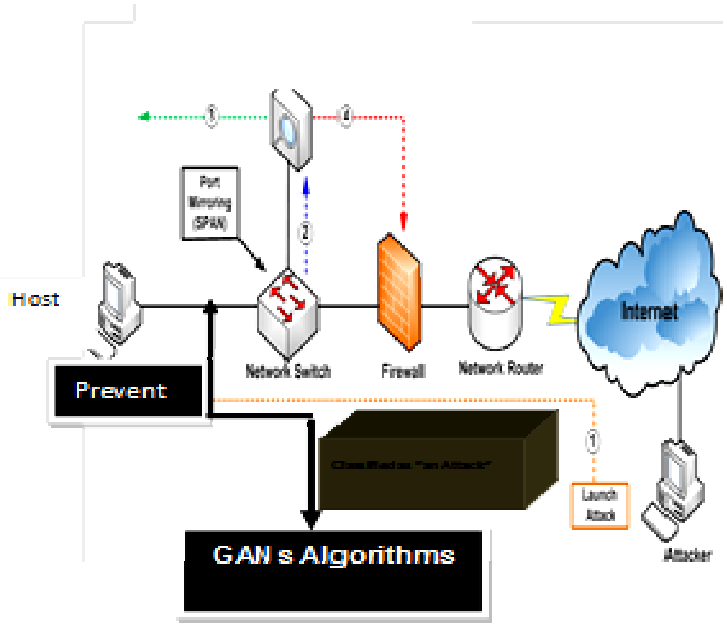

Fig 2: Proposed Intrusion Detection System Architecture

5.3 Tools for System Implementation

The following are the tools to be used in implementing the work: Python Programming Language, Tensor Flow, Linux Operating System, Nmap, hping and wget for network probing.

A detailed analysis of the results comparing the various models from case study of intrusion detection in some selected networks will be carried out.

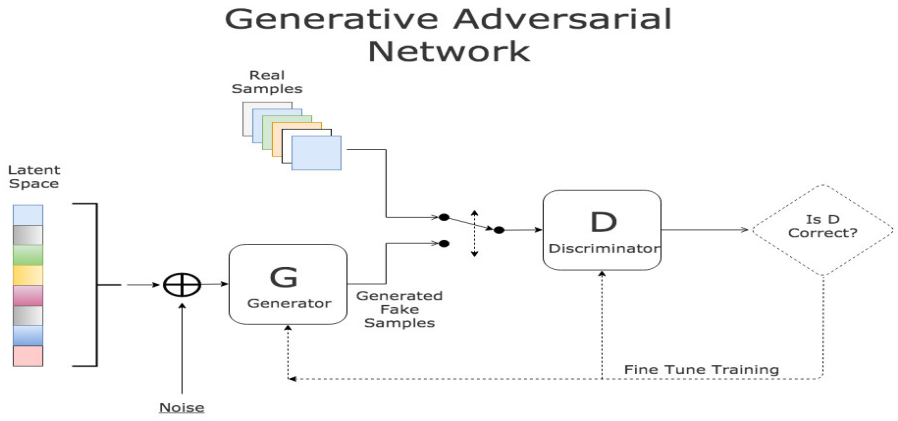

Fig 3: Generative Adversarial Network (Goodfellow, 2016)

6. CONTRIBUTION OF THE RESEARCH TO KNOWLEDGE

The research is expected to:

i. determine attackers' behavioural pattern on a network.
ii. provide an enhanced stochastic security game based intrusion detection model that prevents attackers' actions to be carried out on a network.

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