# Enhancing Intrusion Detection System using XDP with eBPF

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November 15, 2023

# Overview

# Introduction

Network filtering is essential for securing computer networks, and there are various types of attacks that network filtering aims to mitigate. Here are some common network attacks:

- **DOS (Denial of Service) Attack:**
  Attackers flood a network or system with excessive traffic, causing it to become overwhelmed and unavailable to legitimate users.
- **DDOS (Distributed Denial of Service) Attack:** Similar to DoS but conducted from multiple sources, making it even more challenging to mitigate.

**Intrusion Detection System :**

IDS stands for Intrusion Detection System. It is a critical component of a cybersecurity strategy designed to detect and respond to unauthorized access or suspicious activities on a network. IDS is required for several reasons:

- **Security Threat Detection:** IDS helps in detecting and identifying security threats and unauthorized activities within a network or computer system.
- **Network Visibility and Risk Mitigation:** IDS offers insights into network traffic, aids in understanding normal network behavior, and helps reduce the attack surface by identifying vulnerabilities and deviations from the norm.

**What if we use general packet filters ? :**

- Detection Precision :
  This can lead to a higher rate of false positives or missed detections.
- Resource Efficiency :
  consuming more CPU and memory resources.
- Network Performance :
  may introduce more latency and could impact network performance.

# eBPF and XDP

**eBPF (extended Berkely Packet Filtering) :**

- eBPF is a revolutionary technology which origins in the Linux kernel.
- eBPF extends kernel capabilities without altering kernel source code or loading kernel modules.
- It operates as a bytecode-based virtual machine for running programs.
- A verifier assesses the safety of eBPF programs when loaded into the kernel and rejects them if found unsafe.

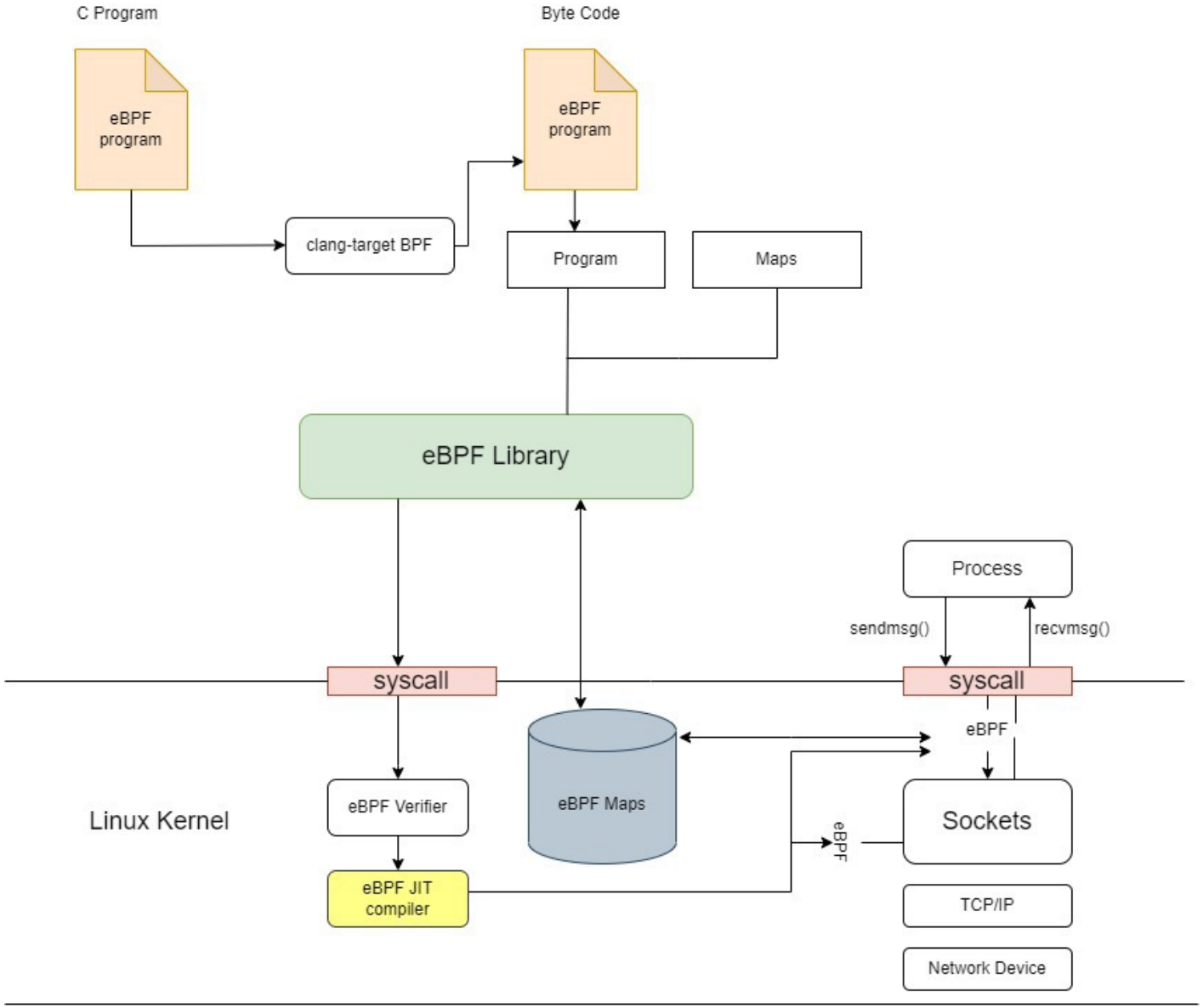



Figure: eBPF Architecture

## XDP (eXpress Data Path) :

- XDP (eXpress Data Path) is a high-performance data processing framework in the Linux kernel.
- It operates at an extremely low level, providing fast packet processing capabilities.
- XDP is commonly used for network filtering, load balancing, and DDoS mitigation.
- It allows for efficient packet handling with minimal overhead, making it ideal for high-speed networking applications.

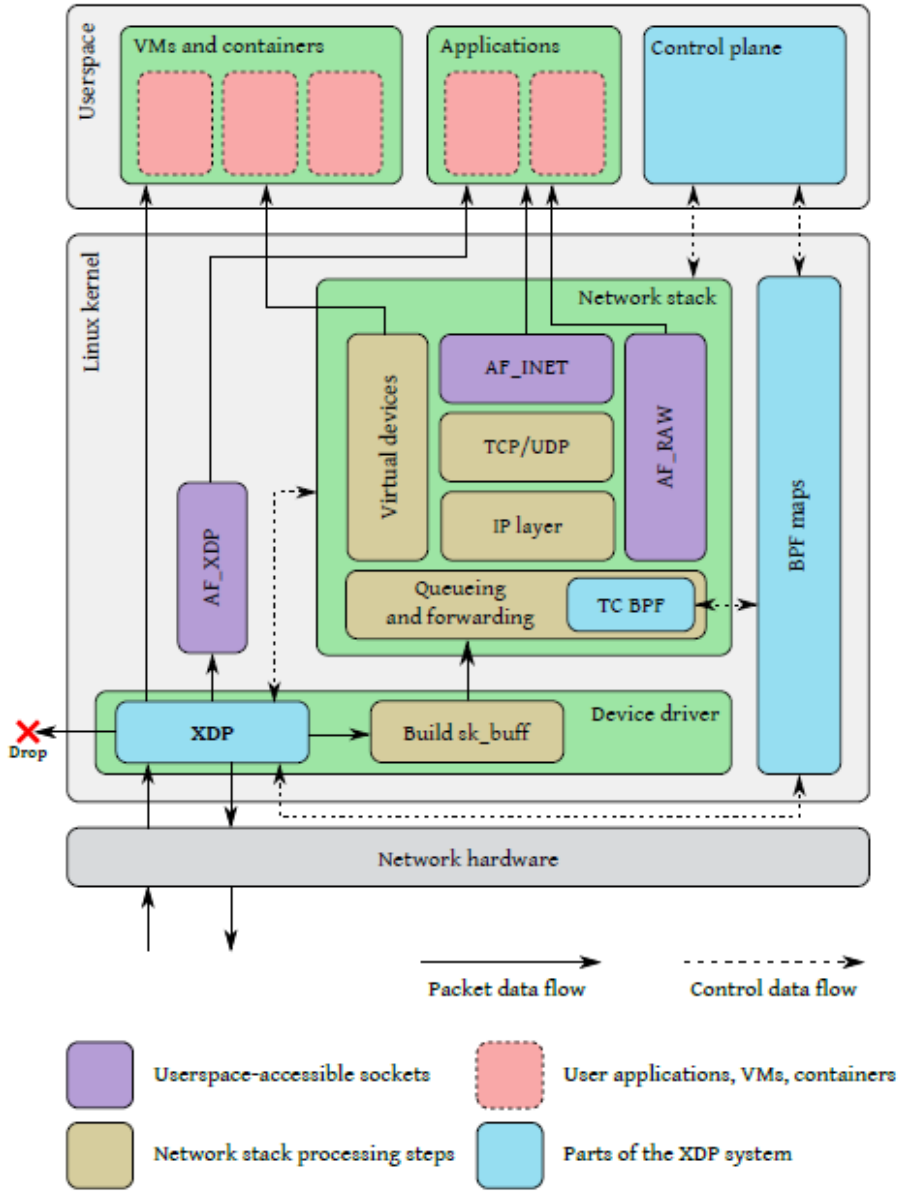



Figure: XDP Architecture

# Literature Survey

| Title | Author | Description | Comments | Year |
|---|---|---|---|---|
| High-performance Intrusion Detection System using eBPF with Machine Learning algorithms [1] | Nemalikanti Anand, Saifulla M A | Intrusion Detection system using eBPF | trained models with DT, RF, SVM, and TwinSVM, obtained low accuracies at userspace | 2023 |
| Intrusion Detection Systems, Issues, Challenges, and Needs [2] | Mohammad Aljanabi, Mohd Arfian Ismail | Machine Learning Algorithms like Decision Tree and Support Vector Machine | analysis of ML algorithms such as ANN, BN, DT, KNN, and SVM, and state weaknesses and strengths for each one that lead to choose SVM | 2021 |
| Fast Packet Processing with eBPF and XDP: Concepts, Code, Challenges and Applications [3] | MARCOS A.M.VIEIRA, MATHEUS S.CASTANHO, R.D.G. PACÍFICO | Resource for understanding and working with eBPF and XDP in the context of network packet | focused on eBPF and the XDP hook, providing examples and showing existing tools or allowing to provide new functionalities | 2020 |

| Title | Author | Description | Comments | Year |
|---|---|---|---|---|
| Design and implementation of an intrusion detection system by using Extended BPF in the Linux kernel [4][5] | Shie-Yuan Wang, Jen-Chieh Chang | The eBPF mechanism has great potential to be used as a framework to implement a high-performance IDS in the Linux kernel. | experimental results show that the maximum throughput of our IDS system can outperform that of Snort by a factor of 3 under many tested conditions. | 2021 |
| The eXpress Data Path: Fast Programmable Packet Processing in the Operating System Kernel [6] | Toke Høiland-Jørgensen, Jesper D. Brouer | XDP design and architecture and how it works is explained | XDP achieves impressive single-core packet processing rates, reaching up to 24 million packets per second. | 2018 |

# Problem Statement

- Attack detecting methods(like IDS, IPS, etc) can detect various application-level attacks (eg.HTTP attacks, DHCP attacks, etc) at network layer.
- In network layer, during packet filtering, there may be loss of data/useful information. (due to DOS attacks, Resource Limitations, Inadequate Throughput, etc ).
- Machine learning algorithms help to classify the normal data and attack data. So that the performance may increase compared to existing methods.

**"So, At what level can we filter the attacks ??"**

# Proposed Method

- The proposed solution is the eBPF (extended Berkely Packet Filtering) technology along with XDP (eXpress Data Path)
- eBPF technology with XDP is used to detect the attacks at kernel level without modifying the source code in the kernel
- Kernel-level packet filtering provides more efficiency in detecting and handling attacks by controlling packet flow at a lower system level ensuring robust security.
- eBPF with XDP analyzes target values from trained models and connects with network devices to make decisions on packet dropping or forwarding.

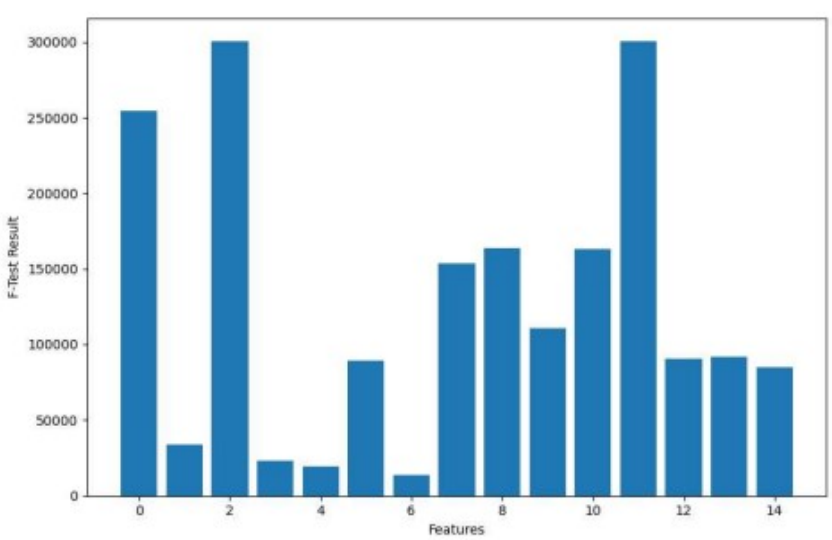
The steps involved in this process are:

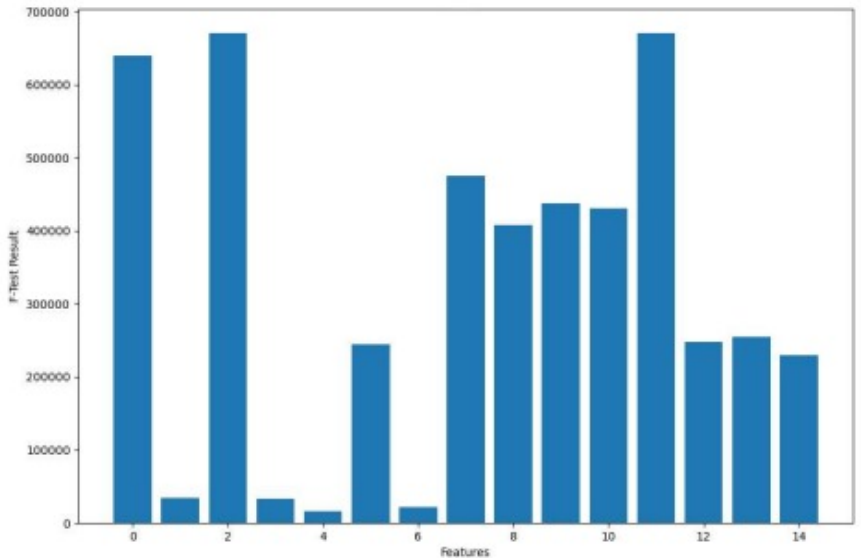
- Identify CIC-IDS-2017 dataset.
- The raw data is then pre-processed, that includes data transmission, cleaning (infinity, NULL values, etc.), and reduction (size).
- Apply ANOVA technique to find top rated features from the pre-processed data
- The extracted features are analyzed for intrusion detection, using ML algorithms (DT, RF, SVM, TwinSVM).
- write an eBPF program(C program) that is converted to bytecode which utilizes trained model parameters to detect attacks.
- write a XDP code with eBPF program that utilizes trained model parameters to detect attacks (filter packets) faster and accurate within the kernel.

# Implementation & Results

- Analyzed the dataset CIC IDS 2017
- Top 15 Features are Extracted from dataset using ANOVA F-test method.
- These features are destination port, total forward packets, total backward packets, minimum packet length, etc.
- All the preprocessed data is trained with Random Forest, Decision Tree, Support Vector Machine, Twin Support Vector Machine.
- The output parameters from trained model are given as input to the ebpf bytecode at kernal level.
- eBPF(extended Berkley Packet Filtering) Bytecode is executed and decide the packet is attack free or not.

# Implementation & Results




Anova F-Test features for DDOS-DOS dataset and CIC-IDS-2017 dataset

# Implementation & Results

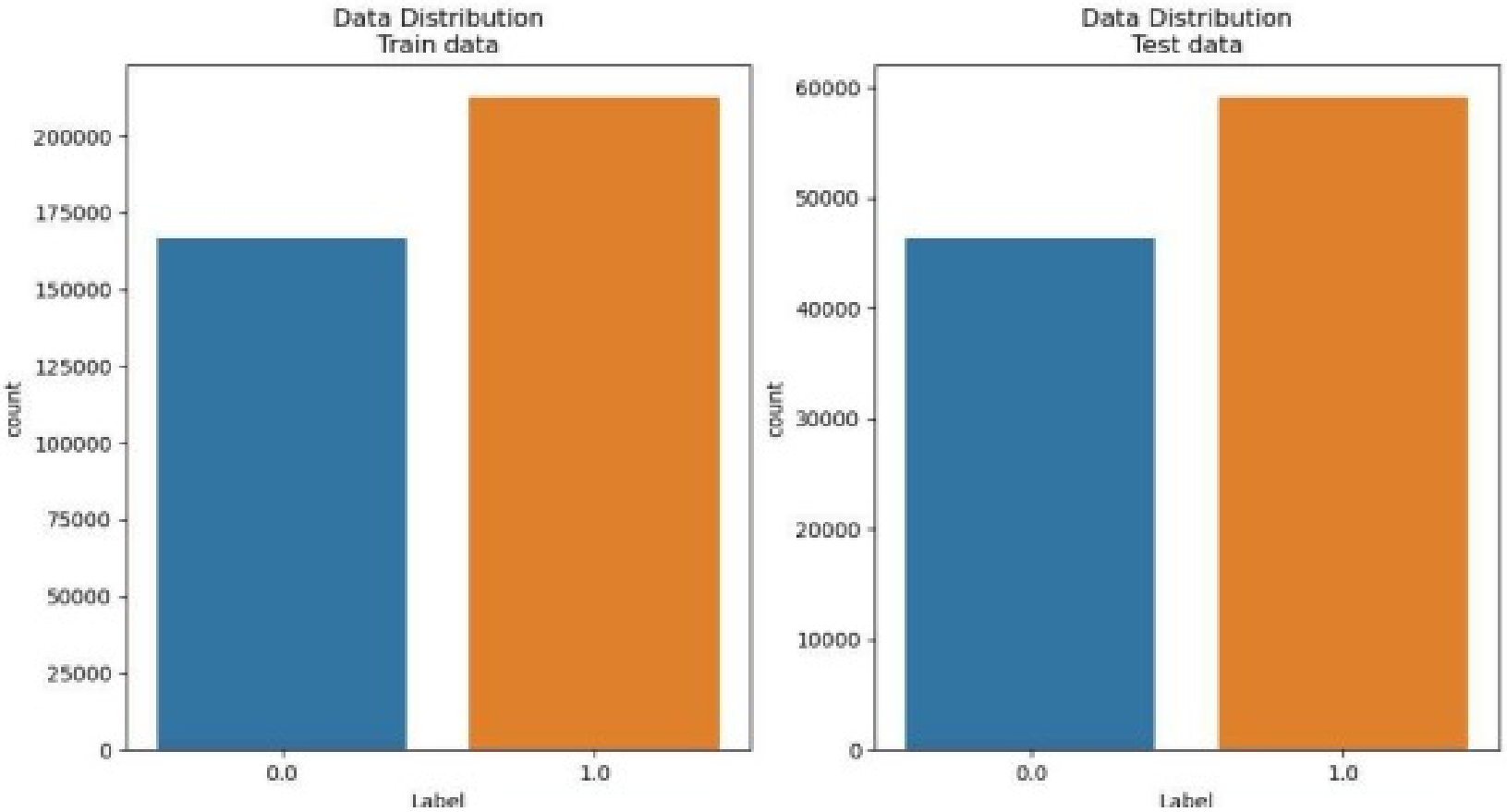
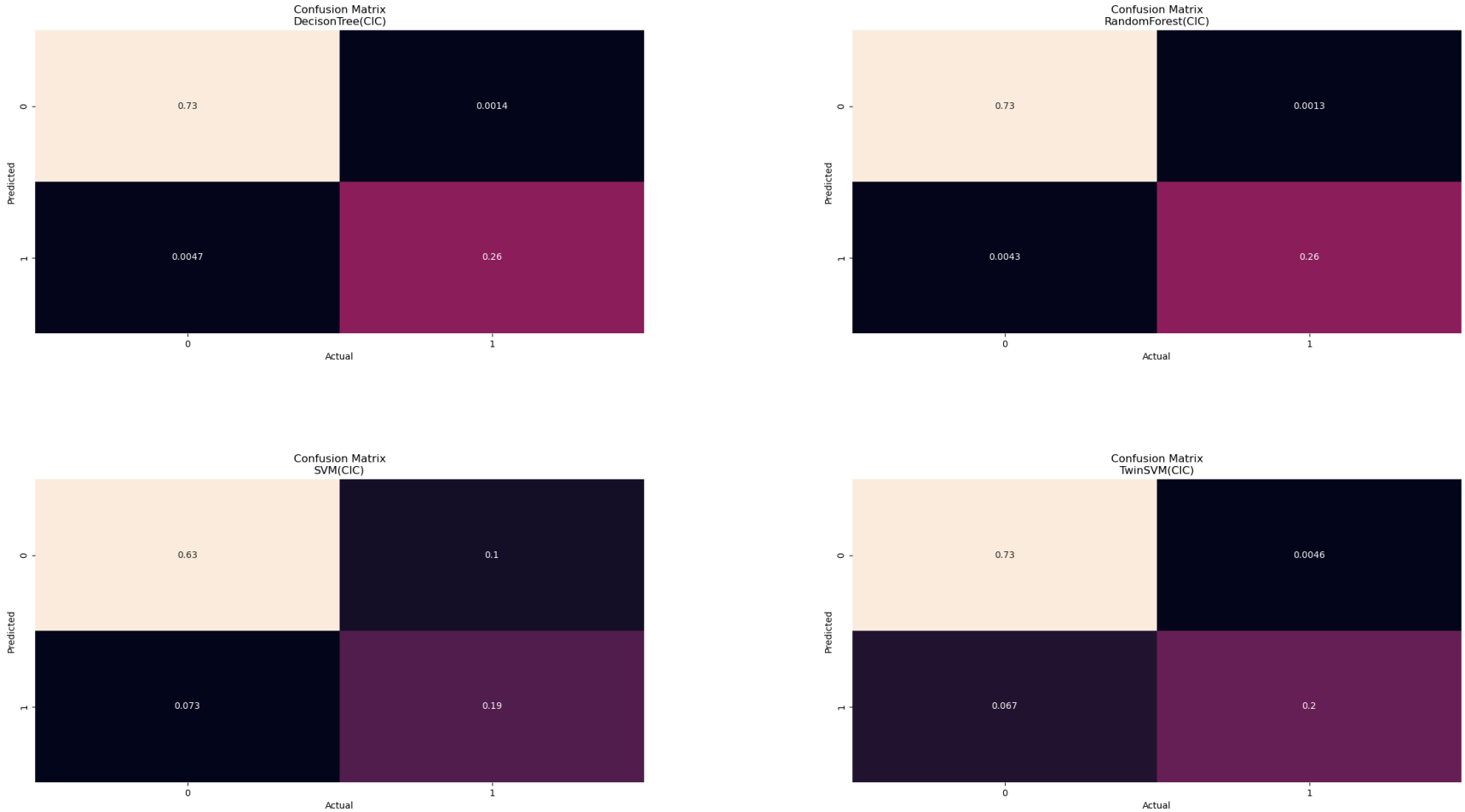



Figure: Data Distribution for DDOS-DOS dataset and CIC-IDS-2017 dataset

# Implementation & Results




Confusion Matrix for CIC-IDS-2017 dataset

# Implementation & Results

| Performance Parameters | Method | DT | RF | SVM | TwinSVM |
|---|---|---|---|---|---|
| Accuracy | Train | 99.52 | 99.59 | 88.77 | 93.87 |
| | Test | 99.38 | 99.44 | 88.74 | 93.82 |
| Precision | Train | 99.71 | 99.74 | 78.97 | 98.58 |
| | Test | 99.46 | 99.51 | 78.97 | 98.49 |
| Recall/ Sensitivity | Train | 98.49 | 98.72 | 73.41 | 75.9 |
| | Test | 98.21 | 98.37 | 73.26 | 75.78 |
| F1 Score | Train | 99.09 | 99.23 | 76.09 | 85.76 |
| | Test | 98.83 | 98.94 | 76.01 | 85.65 |
| Specificity | Train | 99.89 | 99.91 | 93.71 | 99.65 |
| | Test | 99.81 | 99.82 | 93.73 | 99.63 |

| Performance Parameters | Method | DT | RF | SVM | TwinSVM |
|---|---|---|---|---|---|
| Accuracy | Train | 99.73 | 99.82 | 84.43 | 88.49 |
| | Test | 99.57 | 99.58 | 84.43 | 88.42 |
| Precision | Train | 99.87 | 99.88 | 84.28 | 98.53 |
| | Test | 99.71 | 99.65 | 84.31 | 98.49 |
| Recall/ Sensitivity | Train | 99.65 | 99.80 | 86.74 | 79.42 |
| | Test | 99.52 | 99.60 | 86.70 | 79.33 |
| F1 Score | Train | 99.76 | 99.84 | 85.49 | 87.95 |
| | Test | 99.62 | 99.62 | 85.48 | 87.88 |
| Specificity | Train | 99.83 | 99.85 | 81.83 | 98.67 |
| | Test | 99.64 | 99.55 | 81.88 | 98.63 |

Figure: ML performance for cic ids dataset and ddos dos attacks dataset

# Implementation & Results

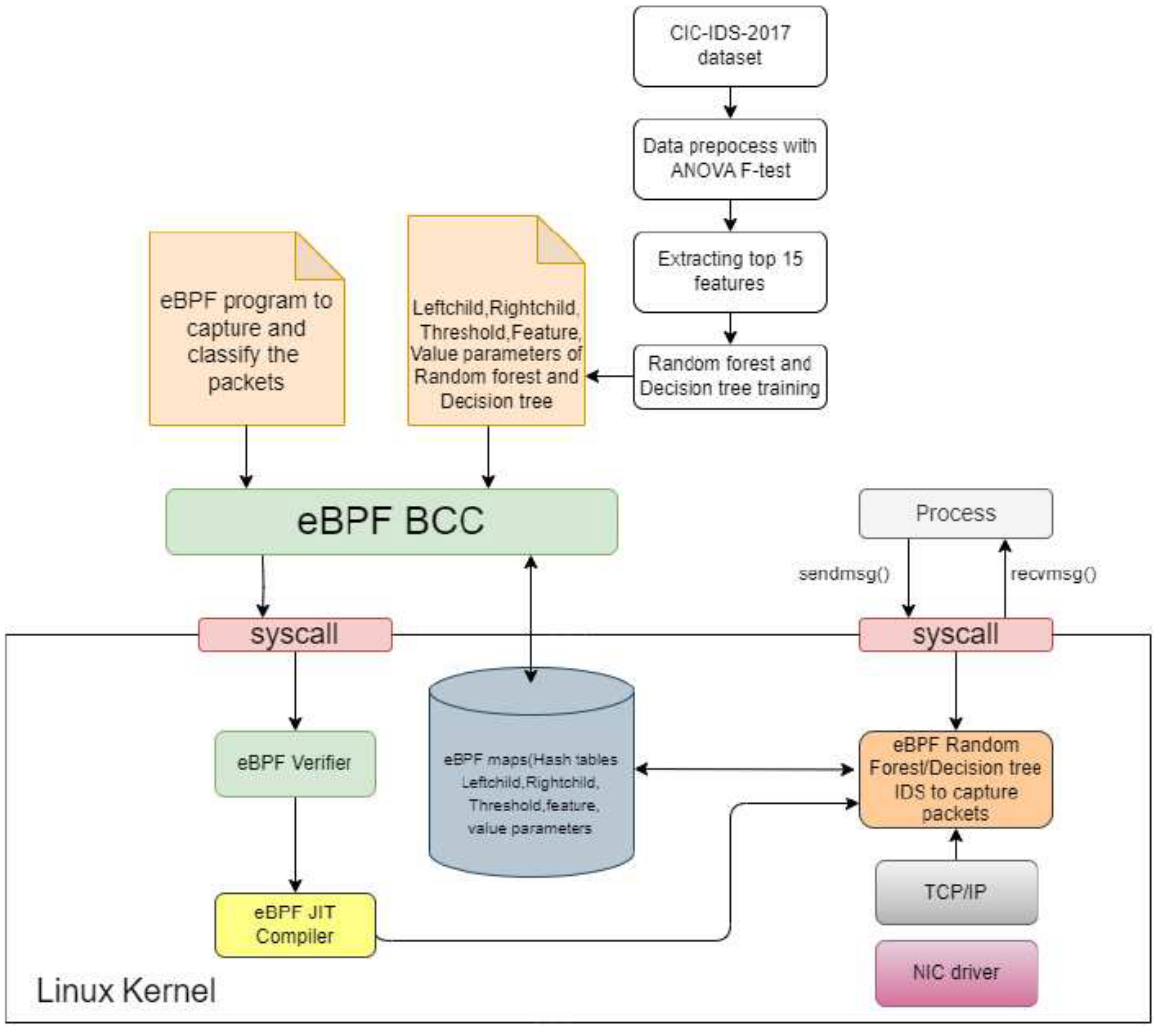



Figure: Proposed model using RF and DT algorithms

# Implementation & Results

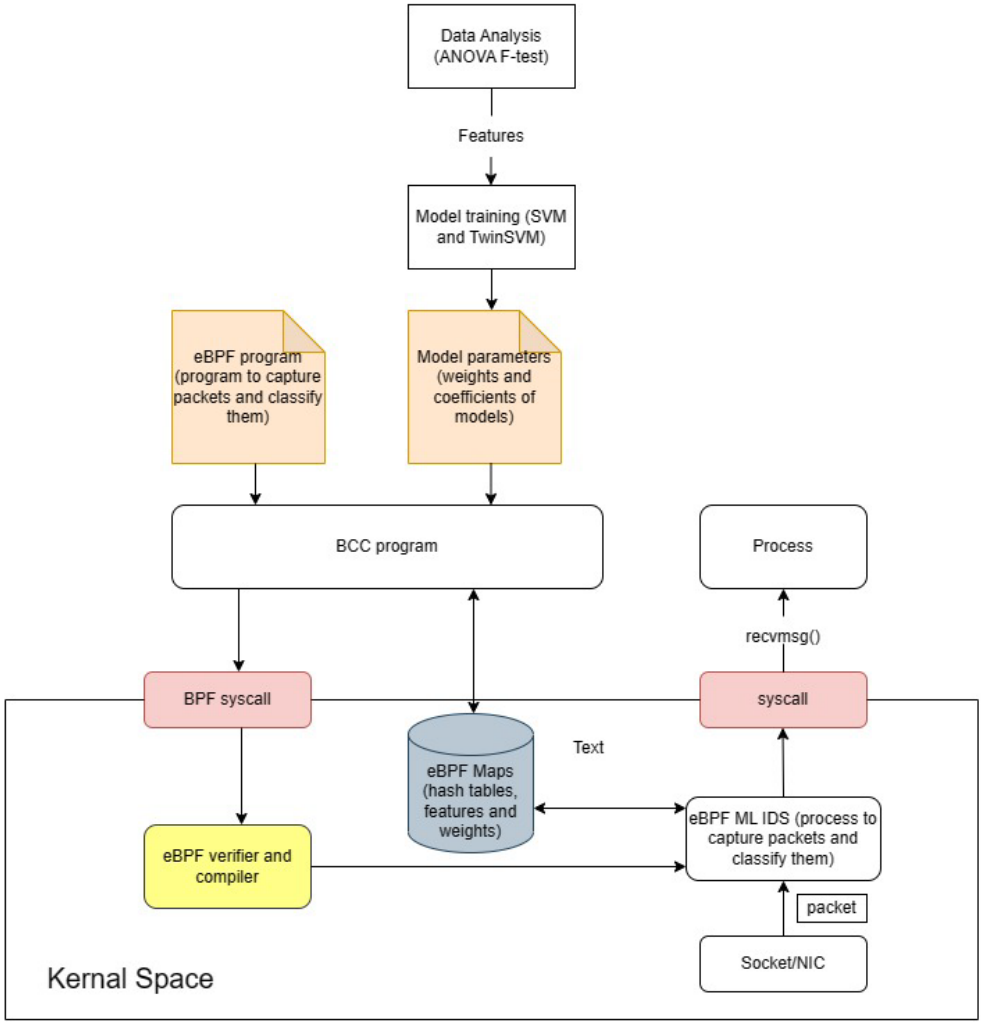



Figure: Proposed model using SVM and TwinSVM algorithms

# Implementation & Results

| Algorithms | Userspace (Mean) | eBPF (Mean) |
|---|---|---|
| Decision Tree packet/s | 46239 | 109691 |
| Random Forest packet/s | 45978 | 108534 |
| SVM packet/s | 45590 | 92978 |
| TwinSVM packet/s | 38430 | 109865 |

Figure: eBPF performance cic ids dataset

| Algorithms | Userspace (Mean) | eBPF (Mean) |
|---|---|---|
| Decision Tree packet/s | 42463 | 106421 |
| Random Forest packet/s | 41632 | 105245 |
| SVM packet/s | 49376 | 92581 |
| TwinSVM packet/s | 42487 | 117536 |

Figure: eBPF performance ddos dos attacks dataset

# Conclusion & Future Scope

- Packets at kernel level are filtered faster than userspace using eBPF technology.
- Using XDP, the arrived packets can be processed before even touching the network stack in the kernel.
- XDP can let the packets bypass the kernel to reach userspace for processing.
- Future scope is to attach XDP with eBPF with other Machine Learning Algorithms.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# Thank you