Distributed Anomaly Detection with Network Flow Data

Detecting Network-wide Anomalies

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Telecooperation Group & CASED

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Table of Contents

Table of Contents

The Importance of Network Security

- Computer networks are crucial to daily life
  - banking systems, power plants, your office
- Attacks are more sophisticated and widespread
- How do we protect networks?
- Proactive security is not sufficient (e.g. firewalls)

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- Security cannot be guaranteed
- Detect security and policy violations after their occurence

Scenario: Small Network

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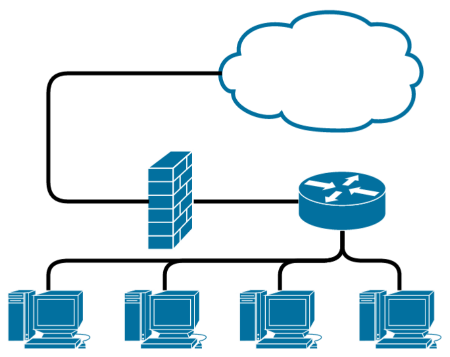

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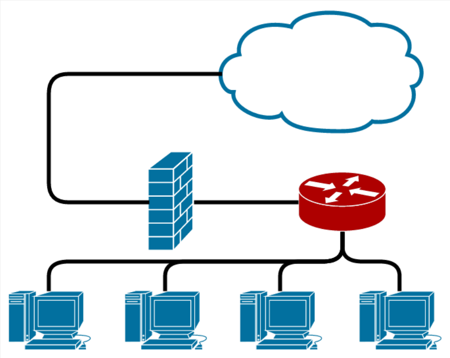

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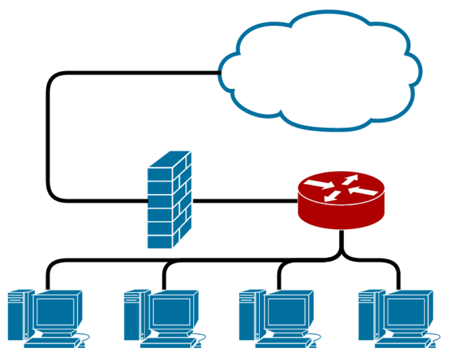

- One common point of ingress
- Complete view of the network
- Flows captured in one place

Reactive Security

Scenario: Large Network

- A distributed monitoring system is required
- Reactive security utilizing **distributed IDSs**

Reactive Security

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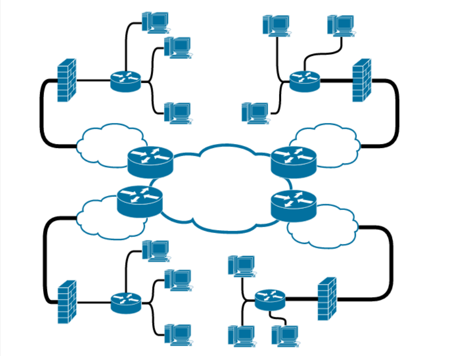

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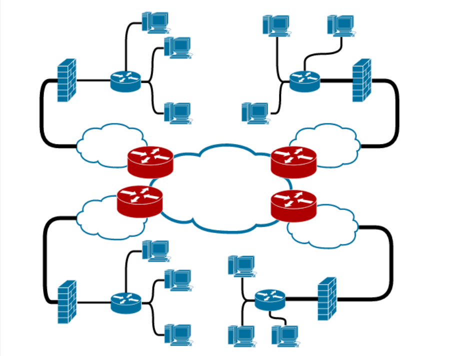

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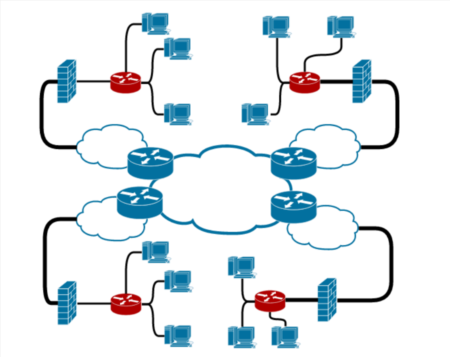

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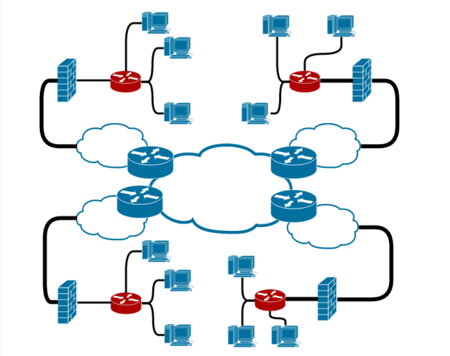

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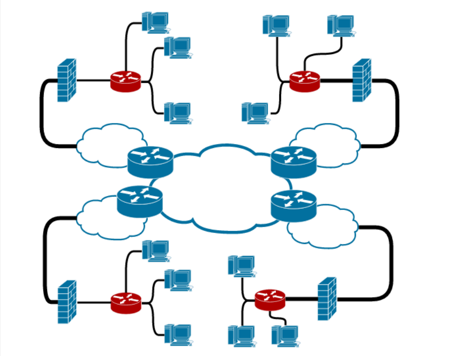

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Distributed Intrusion Detection

Flow Monitoring

- Distributed monitoring with **IsarFlow**
- To collect, aggregate and perform anomaly detection

Anomaly Detection

- To detect unknown problems
  - Attacks or intrusions
  - Irregular operation
- Detect anomalies present in flows

IsarFlow Architecture

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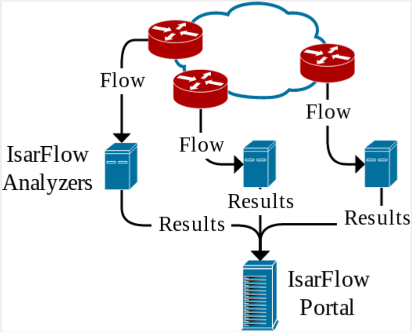

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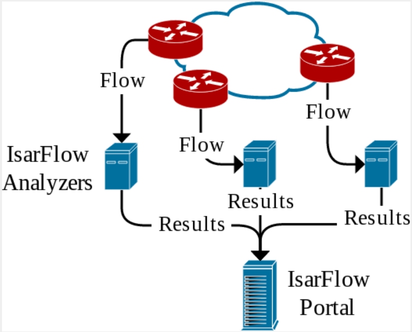

Table of Contents

Anomalies in Network Flows

Flow Anomaly

Any network traffic exhibiting unexpected or undesired patterns of communication in flows.

Common Network Anomalies

- Malicious Activity
  1. (D)DoS
  2. Port Scans
  3. Worms & Botnets
- Operational Problems
  1. Alpha Flows
  2. Ingress Shifts (Outages)
  3. Large quantities of small packets
- Noteworthy Events
  1. Flash Crowds
  2. Bittorrent Traffic

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The Nature of Network Flows

- Highly dimensional data
- Data can be both numerical and categorical (e.g., protocol names)
- Do not contain network payload
- Often contain sampled data
- Vast quantities of information

- Intrusion detection is difficult in this problem space
- Feature extraction and summarization is required

Feature Extraction Strategies

- Volume-based feature extraction
- Entropy-based feature extraction

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- **Entropy-based feature extraction**

Entropy-based Feature Analysis

Why is Entropy Interesting?

- Every flow feature can be summarized with its entropy
  - e.g., source and destination **IP**, source and destination **port**
- Compact representation of all features

Entropy (H):

- Degree of randomness
- Maximum if all values are equal
- Minimal if probability mass concentrates on one value

Shannon Entropy (H)

$$X = \{n_i, i = 1, \ldots, N\}$$

$$H(X) = -\sum_{i=1}^{N} \left(\frac{n_i}{N}\right) \log_2\left(\frac{n_i}{N}\right)$$

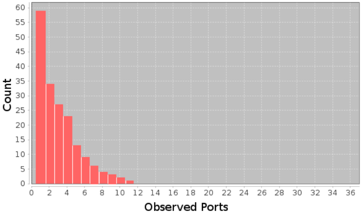
$$0 < H(X) < \log_2 N$$

Entropy-based Feature Analysis

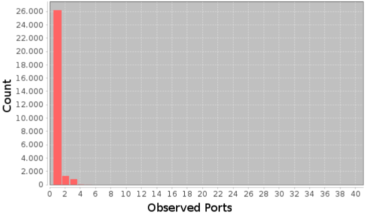
Key Property of Entropy

- Entropy measures the concentration or dispersal of a distribution

Normal Traffic



Port Scan Traffic



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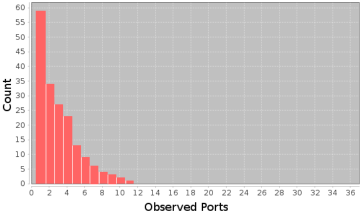

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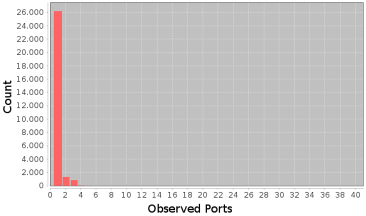

$$H(NormalTraffic) > H(PortScan)$$

Entropy Time Series

Anomaly Detection using Entropy

1. Select a **time window**
2. For each window:
   1. **Build histograms** of the desired features
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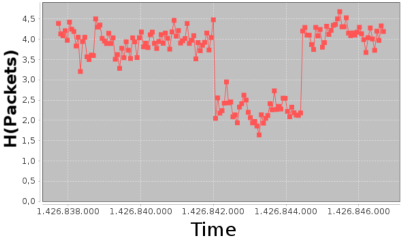

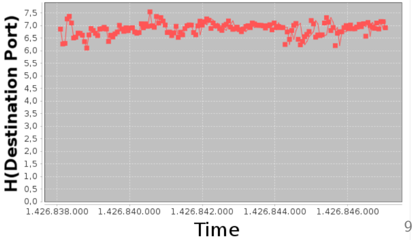

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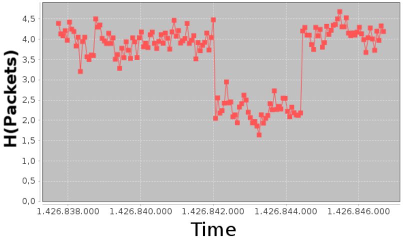

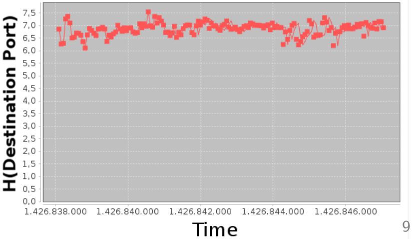

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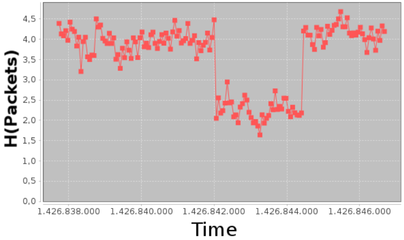

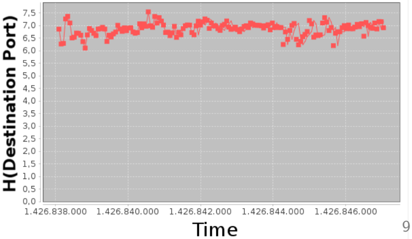

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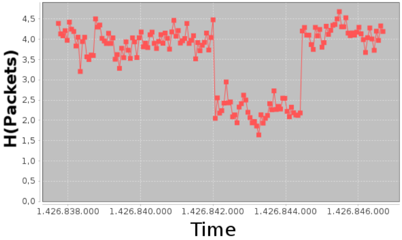

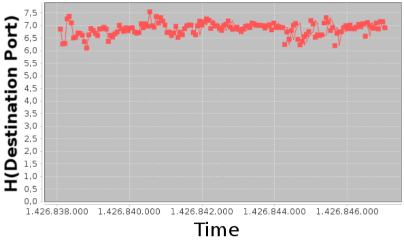

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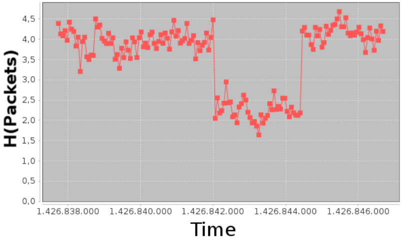

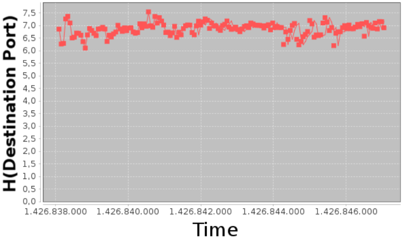

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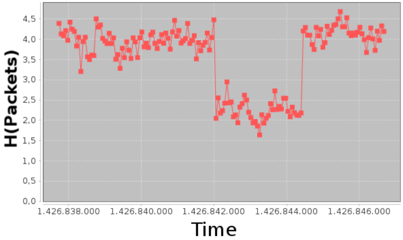


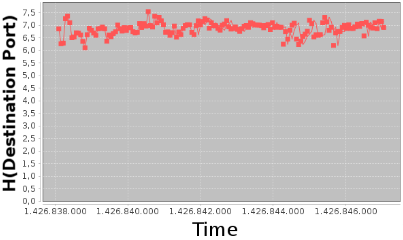
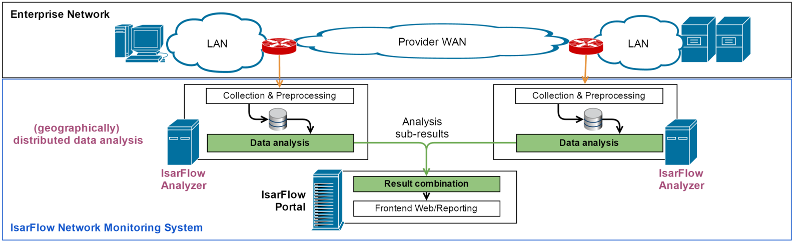


Table of Contents

Distributed Monitoring System

Exemplary architecture: The **IsarFlow** Network Monitoring System

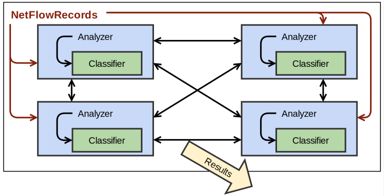


- **Distributed** collection, storage and data analysis
  - Scales very well with more analyzers
  - No need to send flow data across WAN
- Detection Algorithms must also scale in a distributed way

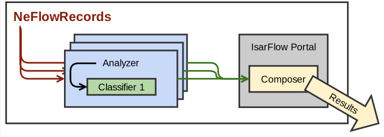
Combination of Models

How to derive models of normality in a distributed system?

Model Merging



Model Compositon



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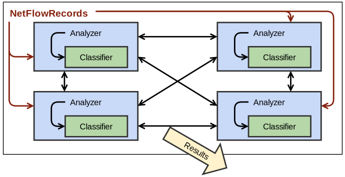
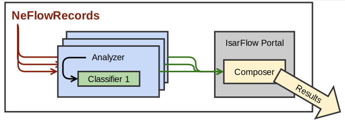


- Calculate features locally
- Exchange features with other analyzers
- Determine global model of normality - based on all feature information

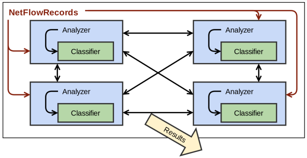
Model Composition



- Calculate features locally
- Train classifier with local features
- Classify traffic with local classifier
- Forward local classification result to evaluation instance (Composer)

Combination of Models

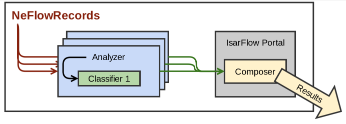
Model Merging



+ Global Model
+ All analyzer utilize same detection model
+ Learned model can be exchanged

- Necessity to exchange feature information
- Features need to be interchangeable

Model Composition



+ Local model might be more precise
+ No feature exchange necessary
+ Smaller overhead

- Model might not be interchanged
- Composer has to be trained

Table of Contents

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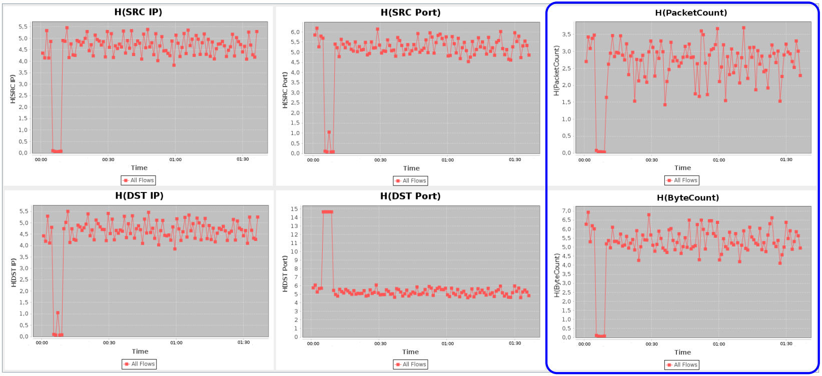

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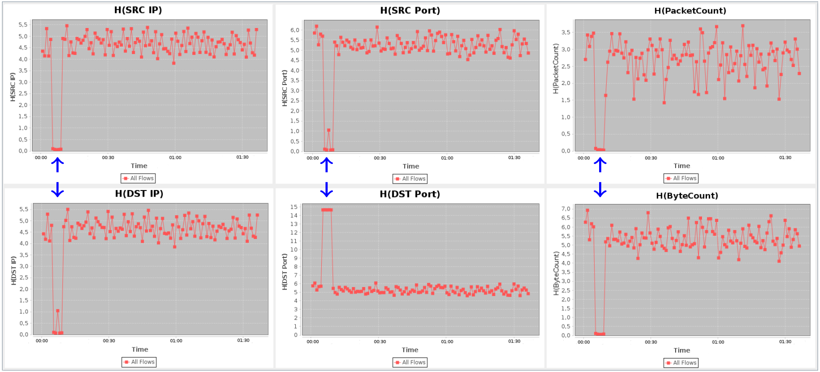


Table of Contents

Summary and Outlook

Summary

- Reactive traffic monitoring is crucial
- Challenges in large enterprise networks
  - Large amount of unsampled flow data
  - Needs distributed collection and data processing
- Entropy as promising feature
  - Difficult to cope with distributed data
  - Approach requires efficient data combination

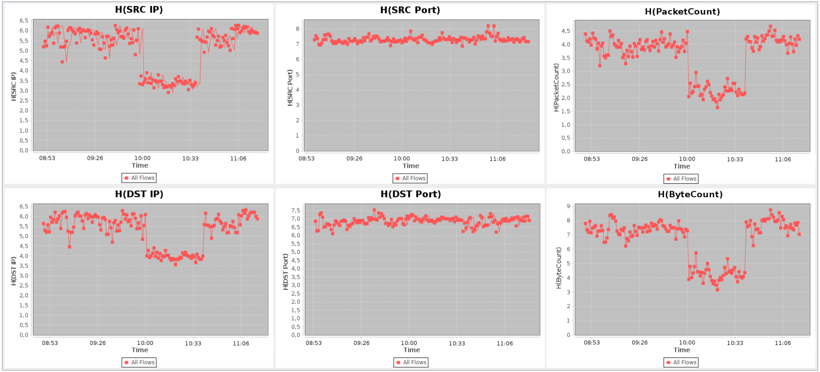
Outlook

- Thorough study of flow data from a large enterprise network
- Evaluation of feature extraction and classifiers
- Study of detection precision and accuracy

Thank you

THANK YOU FOR YOUR ATTENTION

Example: DDoS Reflector Attack detection



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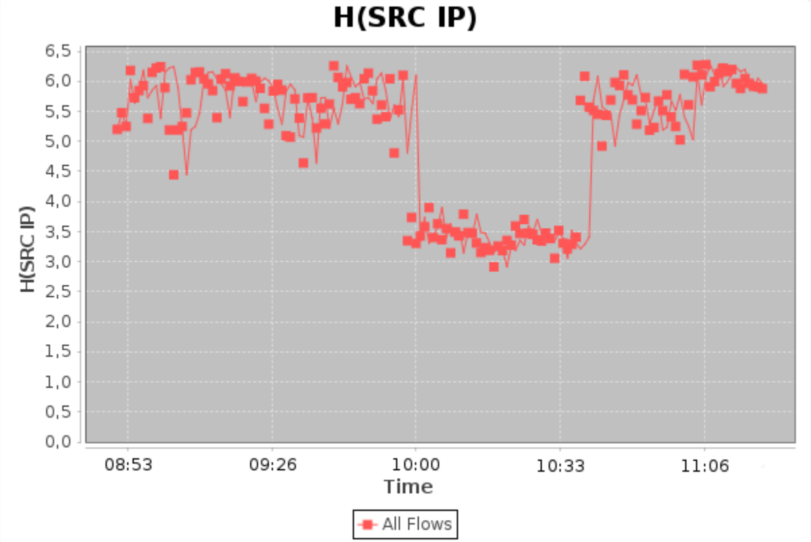

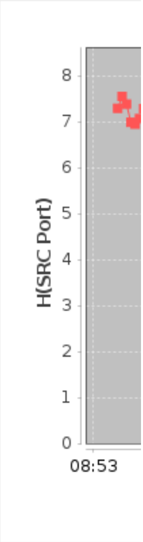

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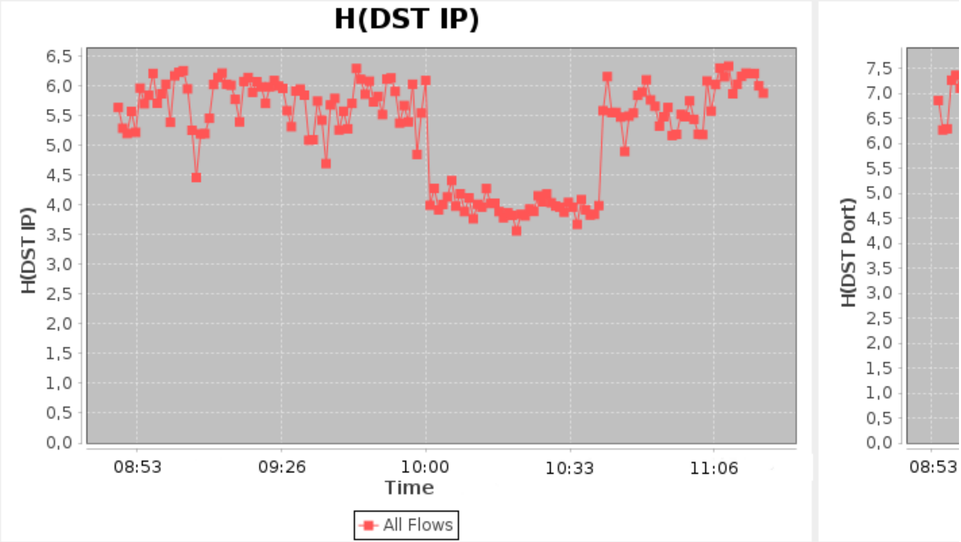

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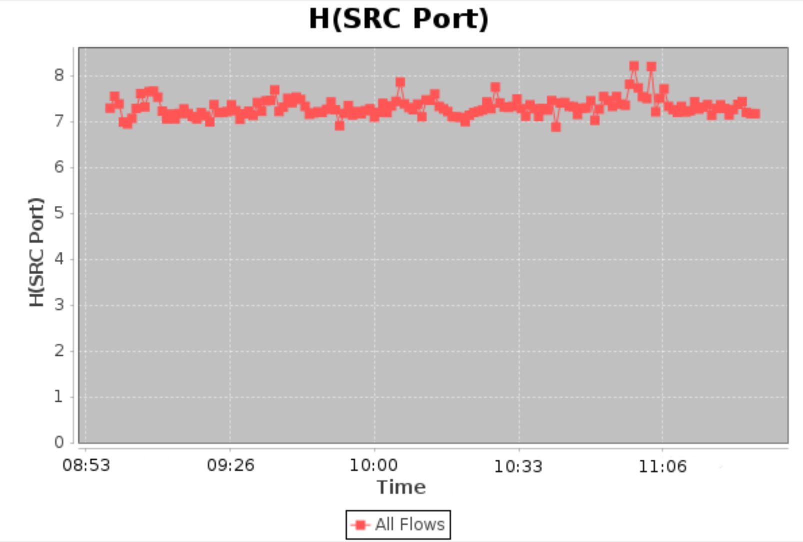
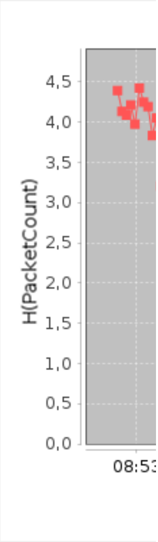
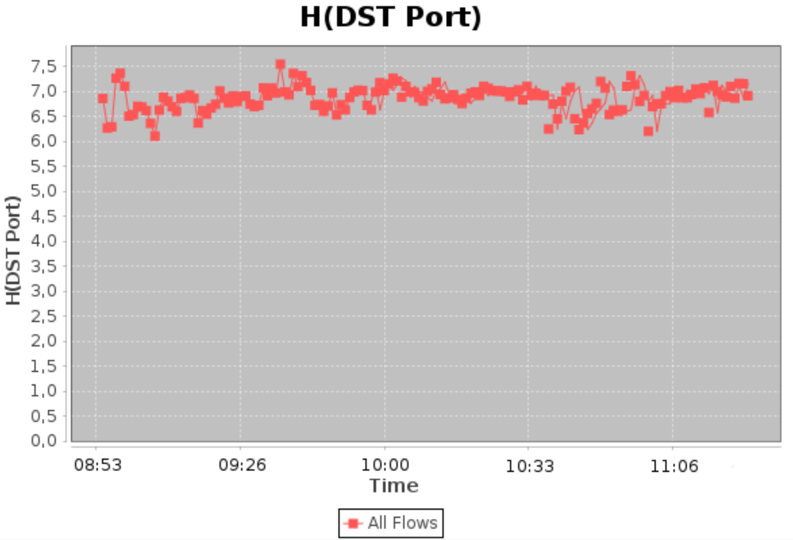
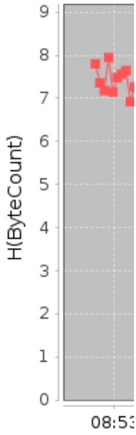


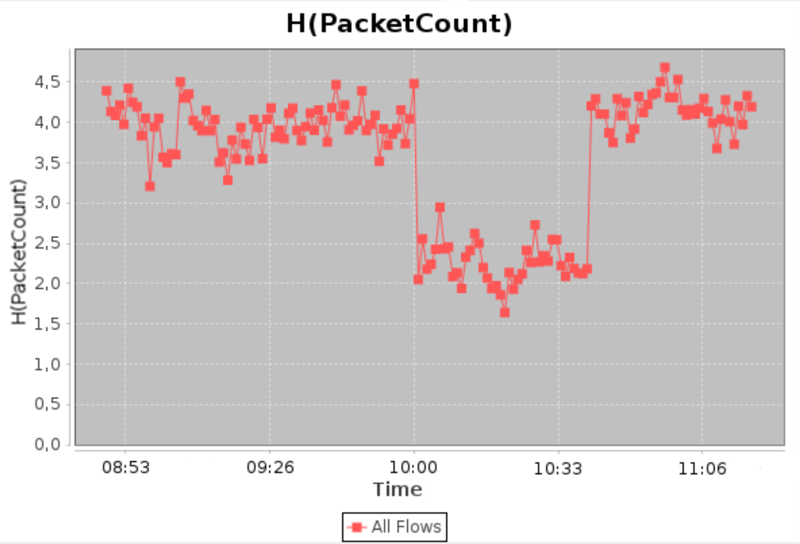


Example: DDoS Reflector Attack detection

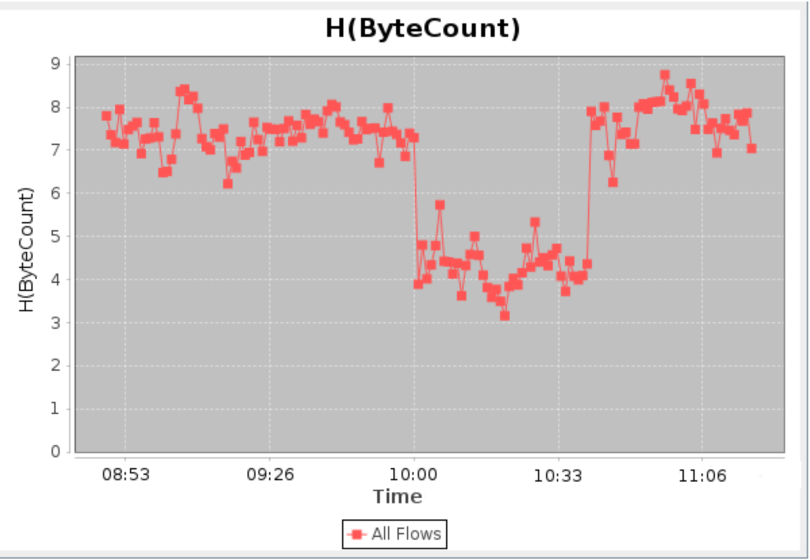




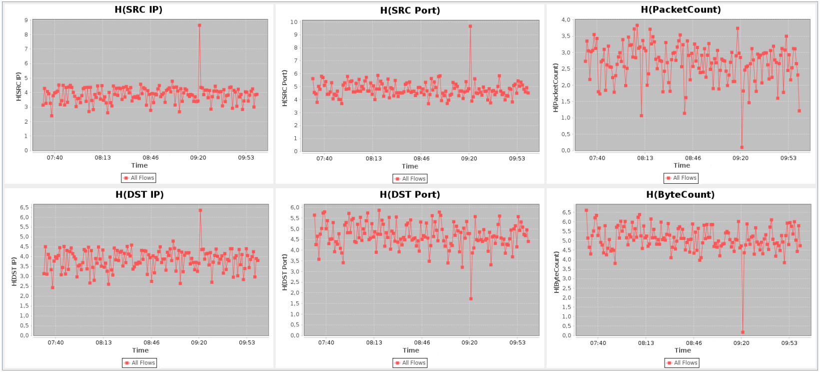
Example: DDoS Reflector Attack detection



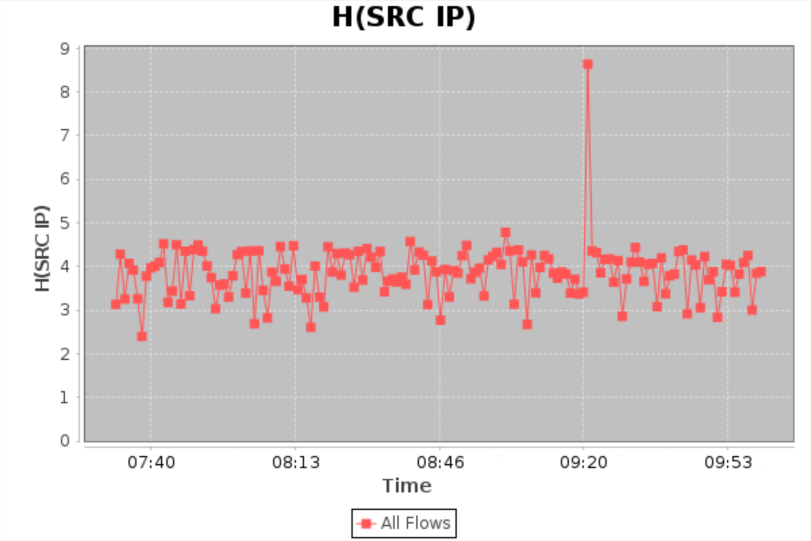
Example: DDoS Reflector Attack detection

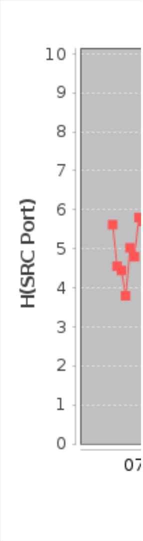


Example: Worm Scan detection

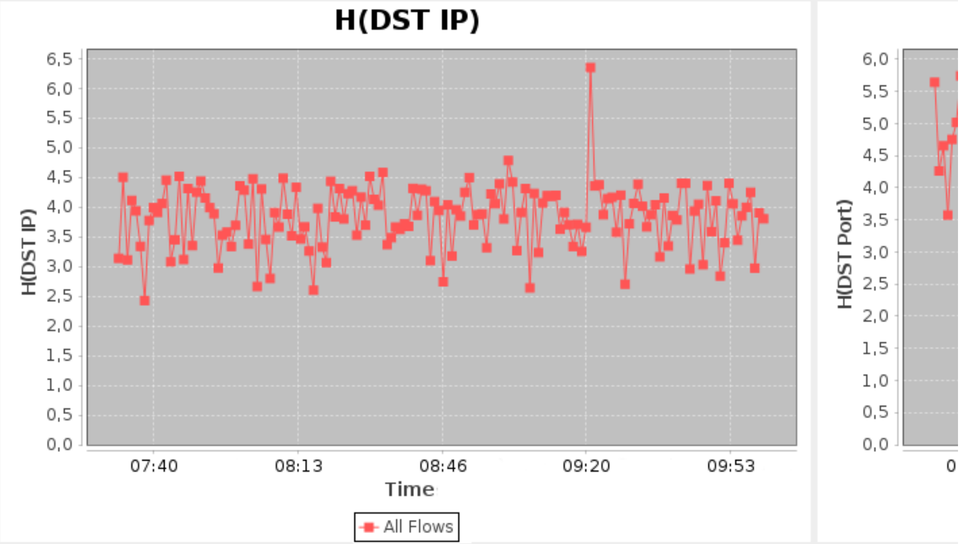


Example: Worm Scan detection

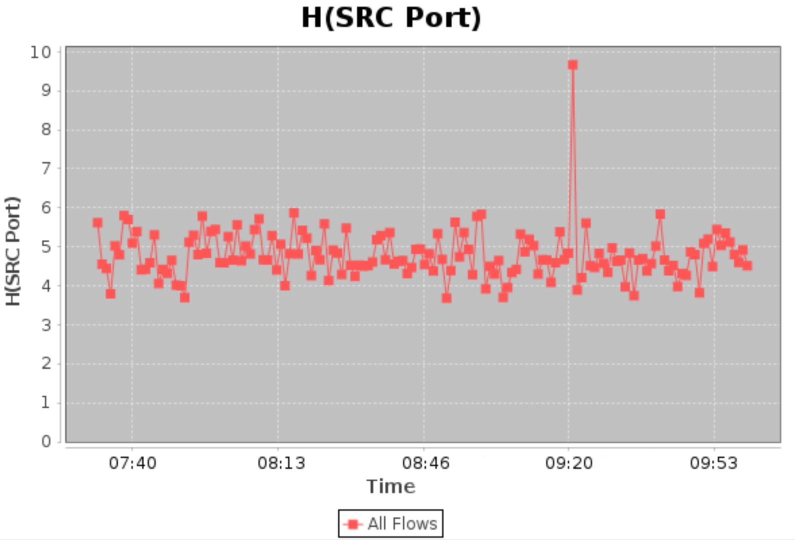


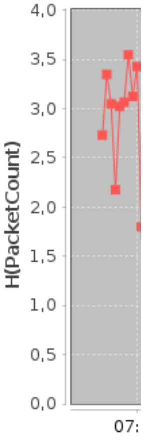


Example: Worm Scan detection

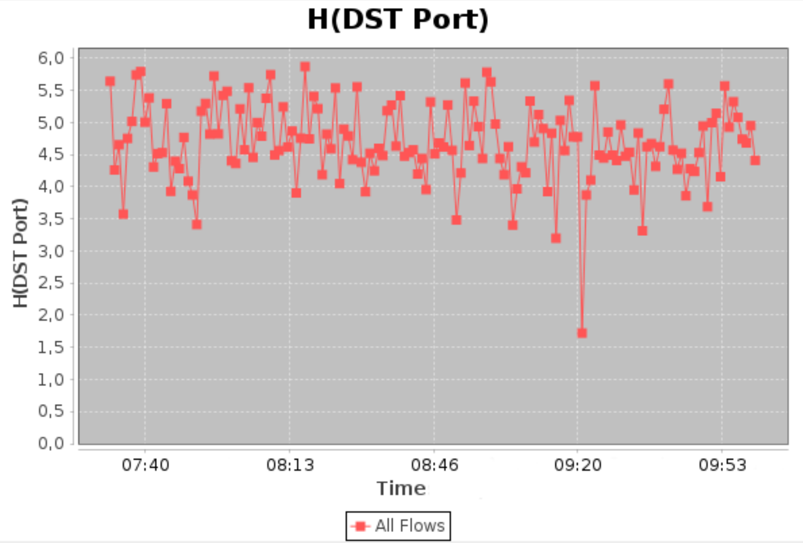


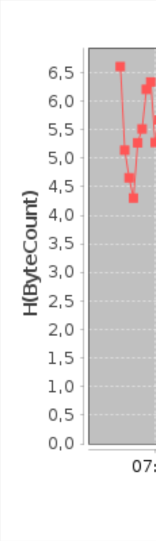
Example: Worm Scan detection



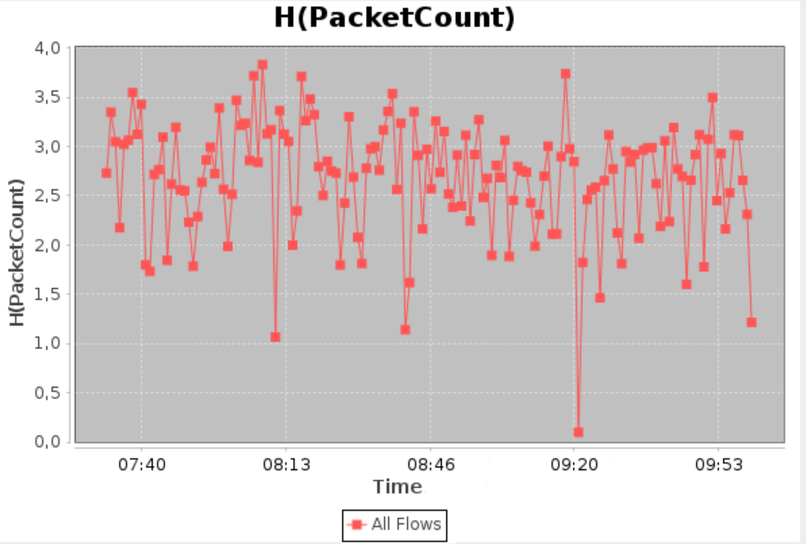


Example: Worm Scan detection





Example: Worm Scan detection



Example: Worm Scan detection