TELECOM SudParis

Institut Mines-Télécom

Distributed Intrusion Detection in Wireless Mesh Networks

Anderson Morais and Ana Cavalli

anderson.morais@telecom-sudparis.eu

MTV2 Meeting

CEA LIST, Saclay, Nov 12, 2012

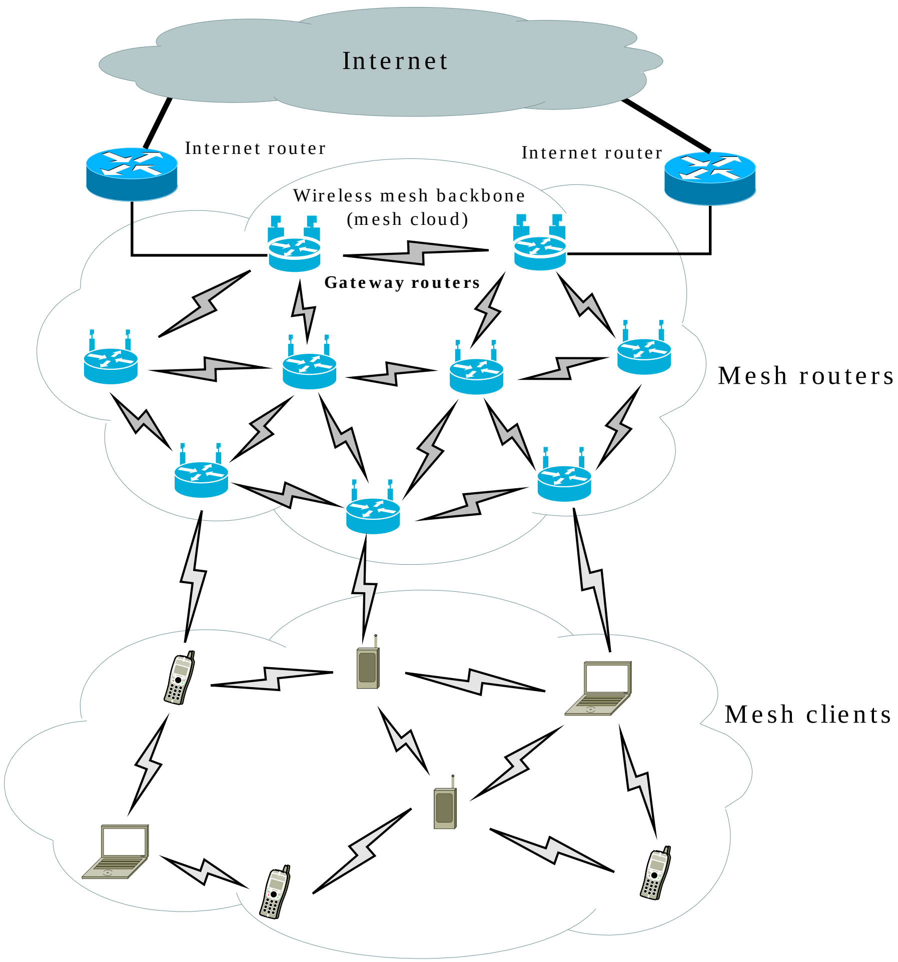
Topics

- Introduction and Motivation
- Distributed Intrusion Detection
- Mesh Network Testing Platform
- Performance Evaluation

Introduction

- Wireless Mesh Network (WMN) is comprised of radio devices **self-organized** in **multi-hop** architecture.
  - The mesh nodes forward packets from others nodes to cooperatively reach a destination (multi-hop strategy).
  - WMN do not rely on a dedicated wireless infrastructure (ex: APs), but the nodes trust on each other to transmit the traffic.
  - WMN is **self-healed**, if a node crashes, then its neighbors establish new routes.
  - Ex.: Wireless Community Networks and Municipal Wireless Networks.

Wireless Mesh Network Architecture



Motivation

- The mesh nodes are vulnerable to:
  - **External Attacks** (ex: *Passive Eavesdropping*, *Jamming*) due to open medium access.
  - External Attacks can be avoided by encryption, authentication, control access, secure MAC, anti-jammers.
  - **Insider Attacks** (ex: *Selective/Random Packet Dropping*, *Selfishness*, *Flooding*, other *Routing Misbehaviors*).
  - A malicious node (with a valid key) can **intercept**, **modify**, **fabricate** and **drop** routing/data packets.
    - Disrupt the integrity of routes and network data services.
    - Consume valuable network resources (ex: bandwidth).
    - Exhaust the hardware resources (CPU, memory) of nodes.

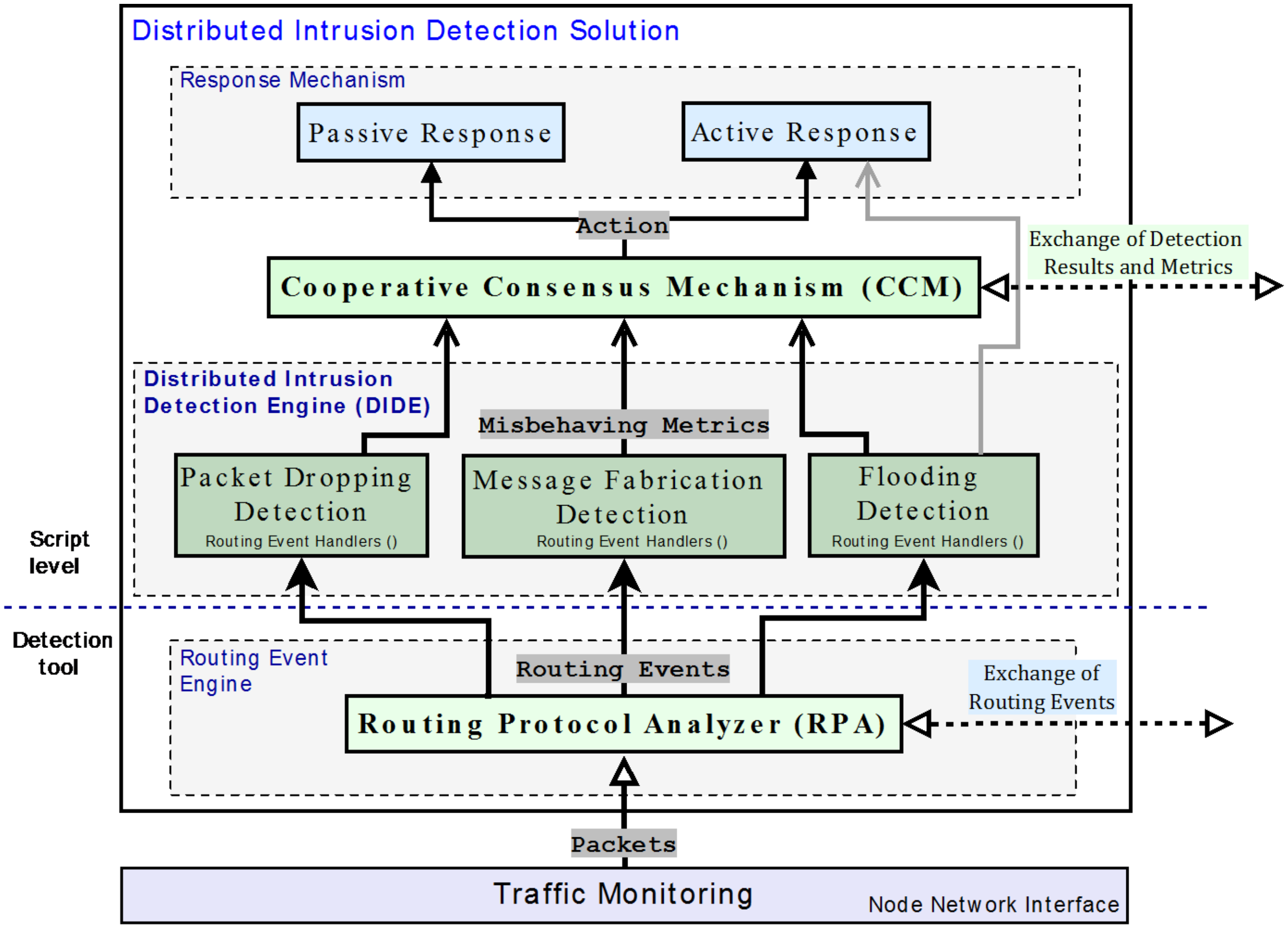
Intrusion Detection

- WMNs needs a **second line of defense** to deal with misbehaving nodes.
- IDSs are classified according to the **monitored events**:
  - *Host-based IDS* (HIDS): monitor the system logs and internals
  - *Network-based* (NIDS): monitor the network traffic
- IDSs are divided depending on the **detection engine**:
  - *Signature-based IDS*: use attack patterns (signatures/rules).
  - *Anomaly-based IDS*: based on normal behavior profile (statistical).
  - *Specification-based IDS*: based on constraints that specify the correct behavior. But can not detect DoS attacks.
- **Our approach** is based on *specification-based IDS: Routing Constraints* optimized for common attacking techniques.

The Intrusion Detection Approach

- An IDS is installed at each node to passively capture and analyze the local traffic: generate *Routing Events*.
- The neighboring nodes exchange *Routing Events* for distributed and collaborative attack detection.
- Each IDS treats the *Routing Events* using *Routing Constraints* to calculate *Misbehaving Metrics*.
- If suspected routing behavior is found, the node triggers the **consensus mechanism** to track the malicious node:
  - The nodes share *Detection Results* and make a collective decision on the node culpability.

Intrusion Detection Architecture



Contributions

- A practical and efficient cooperative intrusion detection architecture for WMNs.
- The **Routing Protocol Analyzer** analyzes routing packets and produces *Routing Events* (protocol behavior).
- The **Distributed Intrusion Detection Engine** treats local and remote *Routing Events* and outputs *Misbehaving Metrics* based on *Routing Constraints* (protocol behavior).
- The **Cooperative Consensus Mechanism** exchanges *Intrusion Detection Results* to cooperatively detect attacks and the source of intrusion (malicious node).
- The approach is implemented into *Bro*[1] IDS tool, and validated through extensive experiments in a virtual mesh network platform.

[1] http://bro-ids.org

Packet Dropping Detection Module

- We use the IDS tool to **monitor** the traffic on the node's network interface (libpcap).
  - We added a filter to select only *BATMAN*[1] **routing messages**.
- A *Routing Event* is a message with parameters as the result of the analysis of a BATMAN **routing packet**.
- Then, the Detection Engine module:
  1. Treats local and remote *Routing Events*
  2. Generates *Packet Dropping Metrics* that indicates an dropping attack is happening.
  3. Exchanges the *Packet Dropping Detection Results* with the neighbors for making joint decisions.

[1] **B**etter **A**pproach **T**o **M**obile **A**d hoc **N**etwork (**BATMAN**) - http://www.open-mesh.org

BATMAN Routing Algorithm 1

1. Each node (Originator - $Orig$) periodically broadcasts **Originator Messages** (**OGMs**) to announce its existence.
   - An OGM has: an $Orig$ Address, a Src Address, a TTL, and a Sequence Number ($Seqn$).
2. As the neighboring node receives an OGM:
   - Modify the Src address to its own address
   - Re-broadcast the OGM according to BATMAN forwarding rules to tell its neighbors about the existence of the node, and so on and so forth.

BATMAN Routing Algorithm 2

3. The mesh network is flooded with OGMs until:
   - Every node has received it at least once.
   - They got lost because of link packet loss.
   - The TTL value has expired.

- The best next-hop to an $Orig$ is the neighbor from which the node received the highest amount of OGMs ($Seqn$) within a sliding window (route quality metric).
  - The routing table of the node contains the best next-hop towards each $Orig$.

Routing Protocol Analyzer

- The Routing Protocol Analyzer analyzes OGMs and generates *Routing Events* according to the protocol behavior:
  - $OGM\_rebrd(< params >)$: the node re-broadcasted a OGM received from a neighbor Nb.
  - $OGM\_rcv(< params >)$: a OGM was received from a neighboring node Nb.
  - $OGM\_broad(< params >)$: the node broadcasts an OGM to its neighbors Nb.
- These *Routing Events* are treated by the node and sent to the neighboring nodes.

TELECOM SudParis

Distributed Intrusion Detection Engine

- The Detection Engine module defines *Routing Event Handlers* that process local and remote *Routing Events* (exchanged with neighbors Nb):
  - $EH\_OGM\_rebrd(\,)\,\{$

    $$Rebrd_{Orig}^{Nb} =+ Seqn;$$

    $$Nb\_Rebrd_{Orig}^{Src} =+ Seqn;\ \ \}$$
  - $EH\_OGM\_rcv(\,)\,\{$

    $$Rcv_{Orig}^{Nb} =+ Seqn;$$

    $$Nb\_Rcv_{Orig}^{Src} =+ Seqn;\ \ \}$$

Routing Constraints

- We define *Routing Constraints* based on the protocol behavior to detect malicious Packet Dropping PD :
  - $EH\_OGM\_rcv(\,)$:
    - $\mathrm{C1} =$ “Check if the $Seqn$ received by the node from Nb for $Orig$ will be rebroadcasted by own node”:
      - **if** $Seqn \notin Rebrd_{Orig}^{Nb}$ **then** PD_{Rebrd}++
    - $\mathrm{C2} =$ “Check if the $Seqn$ received by its Nb from Src for $Orig$ will be rebroadcasted by Nb”:
      - **if** $Seqn \notin Nb\_Rebrd_{Orig}^{Src}$ **then** PD_{Nb_Rebrd}++

Packet Dropping Metrics Calculation

- Then we calculate the Rate of Packet Drop routing misbehavior R for the *Routing Constraints*:
  - For C1 at $EH\_OGM\_rcv(\,)$:

$$-R_{Rebrd} = \frac{PD_{Rebrd}}{|Rcv|}$$

  - For C2 at $EH\_OGM\_rcv(\,)$:

$$-R_{Nb\_Rebrd} = \frac{PD_{Nb\_Rebrd}}{|Nb\_Rcv|}$$

Consensus Mechanism

- *Packet Dropping Metrics* are constantly monitored by the Consensus Mechanism module.
- If suspected **Packet Dropping Attack** is found, the neighbors exchange respective *Dropping Metrics* and share *Detection Results* before a final decision is taken.
  - To avoid inaccurate detection results because of poor link quality due to interference and congested links.
- If a **consensus** is reached with majority agreement, then the malicious node is detected.
  - The *decision rule* is “unanimous agreement minus one vote or two votes”.

Cooperative Consensus Mechanism

- A **threshold** Th is defined to separate the **detection rate** from the **false positive rate** (caused by the loss of messages) :
  - **if** $(R_{Rebrd} \geq Th_{Rebrd})$
    1. Node 1 (O_1) detected the malicious dropping PD_{Rebrd};
    2. O_1 triggers the **consensus**;
    3. **Sync** $(R_{Rebrd}, R_{Nb\_Rebrd})$ with the Neighbors N_i; $1 \leq i \leq k$
    4. **for** all N_i { if $R^{N_i}_{Nb\_Rebrd} \geq Th^{N_i}_{Nb\_Rebrd}$};
       1. **Sync** (MN_{O_1}, MN_{N_i});
       2. **if** $(MN_{O_1} = MN_{N_i})$ **then consensus** is done.

[1] MN: Malicious Node

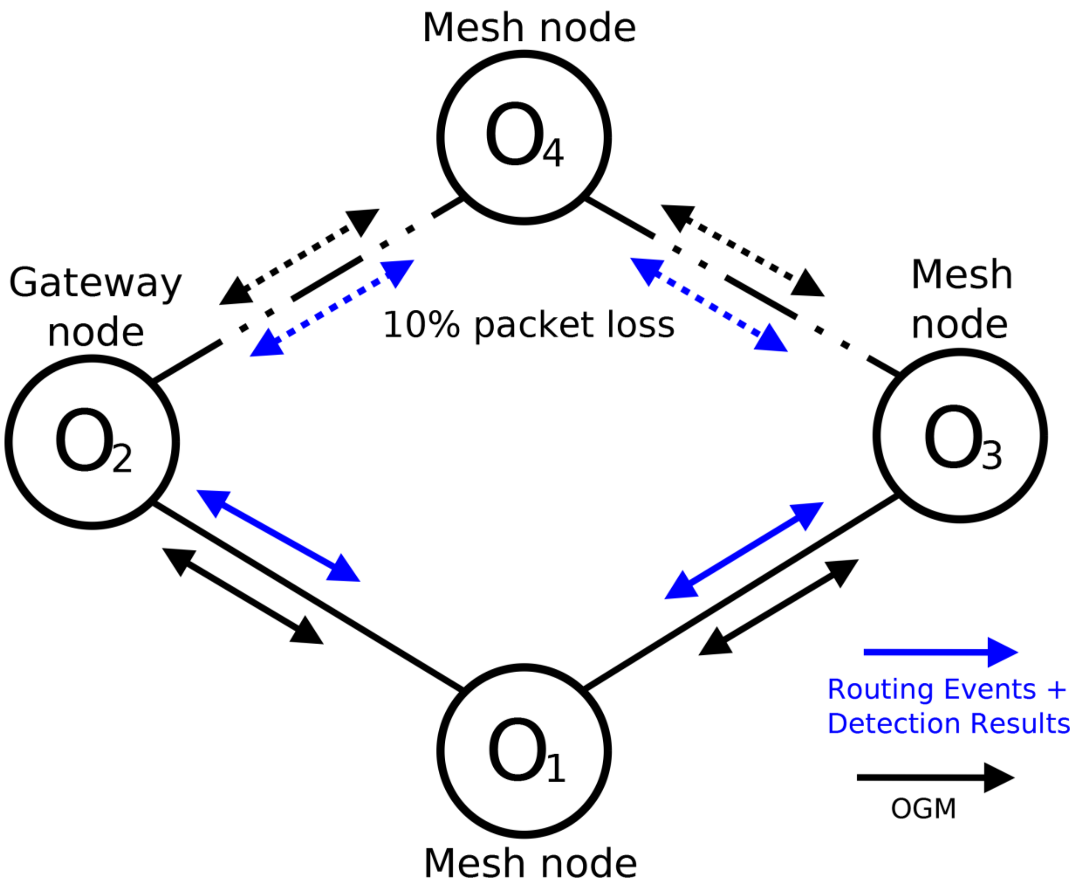
TELECOM SudParis

Virtualized Mesh Network Platform

- We use a **virtual network environment** to emulate the mesh network toplogy:
  - Each node is a **VM**[1] running BATMAN[2] proactive routing protocol as Linux Kernel module.
  - The VMs are interconnected by a *virtual switch*:
    - To emulate *Bi-directional Links* between nodes;
    - Realistic Link Limitations: packet loss rate, lost burstiness.
  - We collect log files and pcap files at each node that are synchronized by the *global clock* of main machine.
- This platform represents the performance requirements of the IDS in terms of hardware resources and accuracy.

[1] http://wiki.qemu.org
[2] http://www.open-mesh.org

Performance Evaluation: Scenario



- Before the attack:

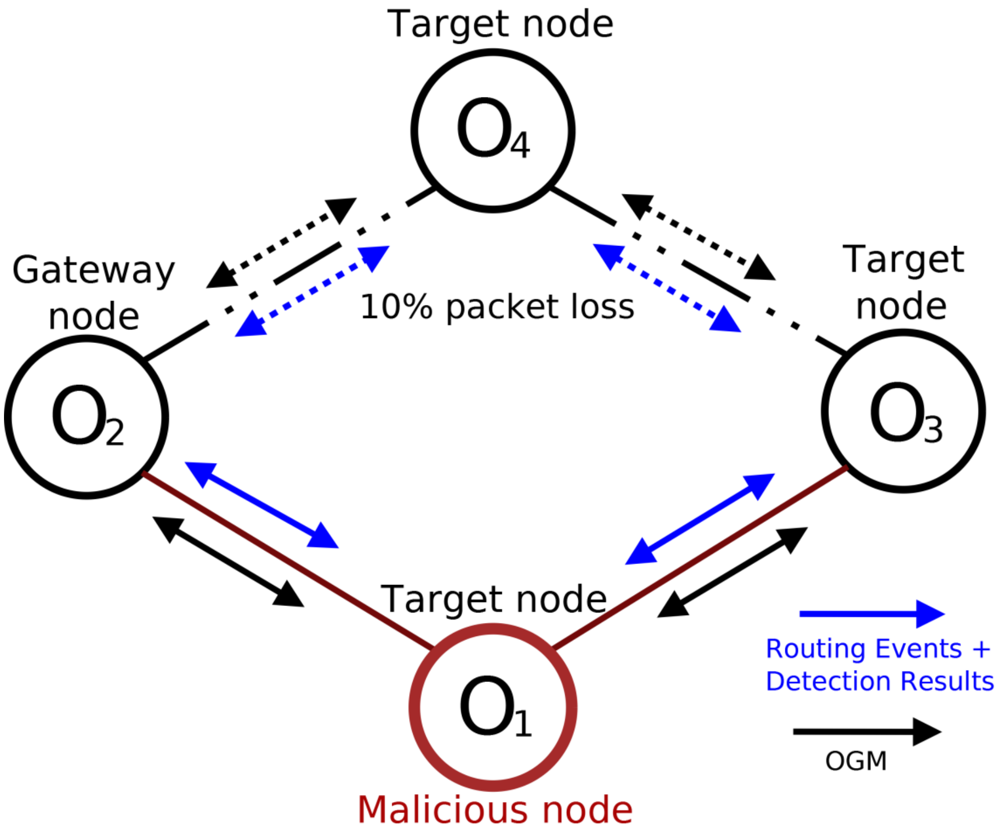
- Node O_3's Routing Table:

Destination	Best Next-hop
O_2	$\boldsymbol{O_1}$

Packet Dropping Attack

- The malicious node O_1 drops the OGMs rebroadcasted by the own node O_1 for node O_2.
  - Node O_3 will then choose node O_4 as best next-hop to gateway node O_2.
  - Then if node O_4 is compromised, it can execute black hole or gray hole attacks by dropping the data packets.
- The ***Packet Dropping Attack*** violates the integrity of the Routing Table of the target node.
- The attack is implemented in the *virtual link* between nodes O_1 and O_3 by using a filtering scheme.

Dropping Detection Evaluation



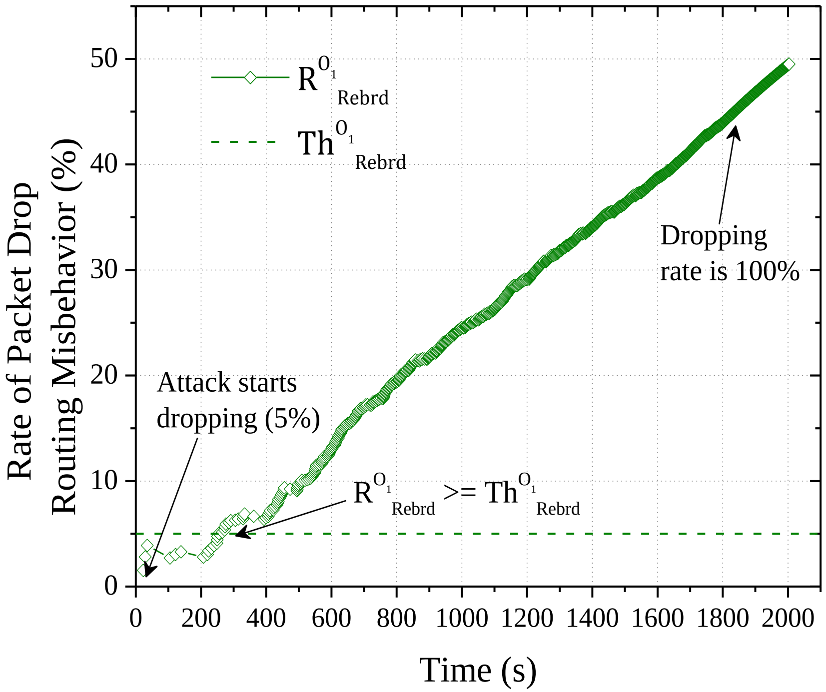
- After the attack:

- Node O_3's Routing Table:

Destination	Best Next-hop
O_2	$\boldsymbol{O_4}$

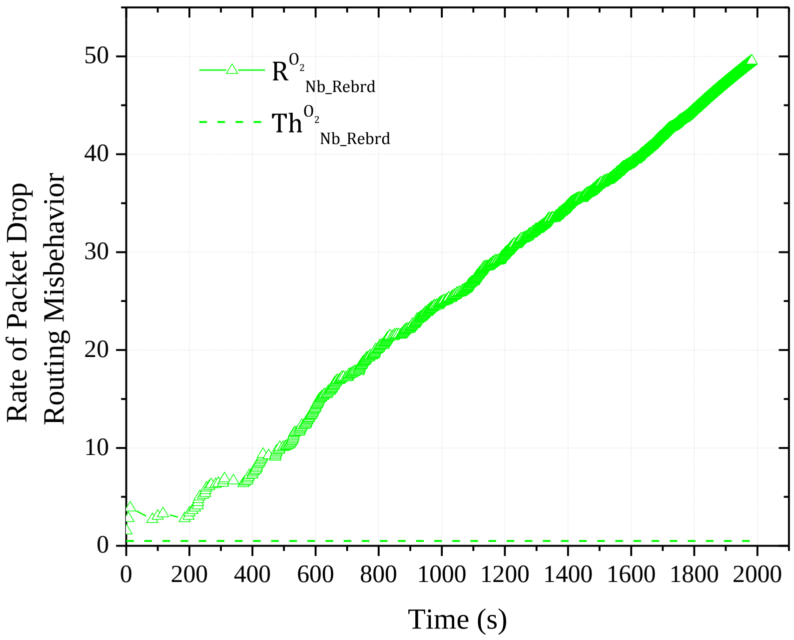
Packet Dropping Detection at node O_1

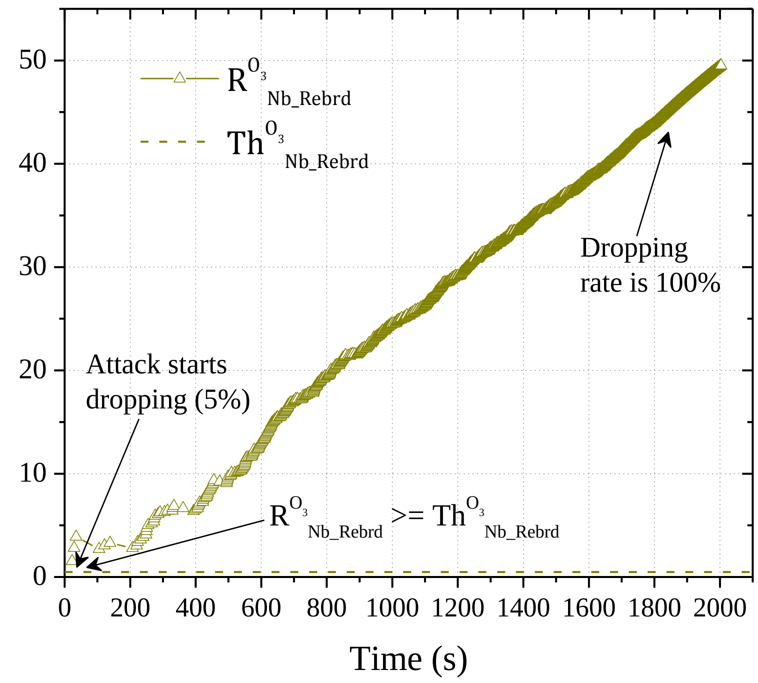
- Rate of Packet Drop R_{Rebrd} detected at node O_1.
  - The malicious node O_1 drops 5% OGMs at 180 secs, 10% OGMs at 360 secs , 20% at 540 secs , until 100%.



Packet Dropping Detection at nodes O_2 and O_3

- Rate of Packet Drop R_{Nb_Rebrd} detected at node O_2 and node O_3.





Future work

- Implement Active Response Mechanisms to mitigate and/or block the attacks.
- Reduce the Communication Overhead without impacting the attack detection accuracy.
- Implement mobility models in the platform to evaluate the approach.

Thank you !