# TOPHAT: Topology based Host-Level Attribution for Multi-Stage Attacks in Enterprise Systems using Software Defined Networks

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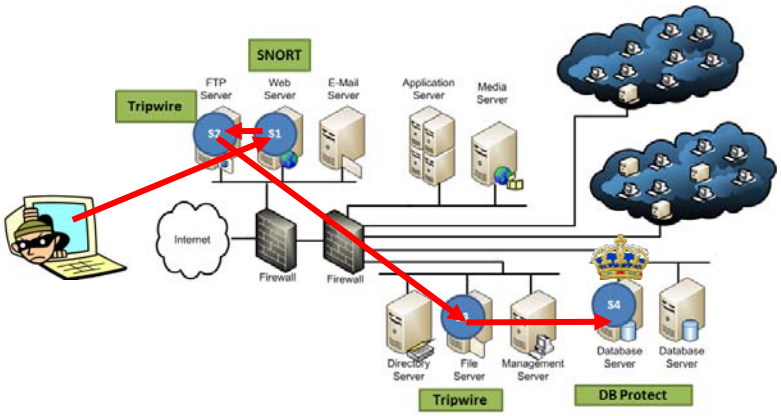
## Outline

- Background: Multi Stage Attacks
- Problem Statement: Attribution Problem
- Prior Work
- Our Solution
  - Contribution
  - System Model, Attacker Model
- Solution Variants:
  - Uniform Risk Assignment Algorithm
  - Low Risk Isolation Algorithm
- Results
- Conclusion and Future Work

# Background: Multi Stage Attacks (MSA)

- Multi Stage Attacks utilize multiple victim machines in a series, to compromise a target machine deep inside the enterprise network.
- First, the attacker compromises an outward facing service by exploiting a vulnerability in it.
- Then uses the access privilege on that compromised service to proceed to rest of the network in a step by step manner until the crown jewel is compromised.

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3

# Problem Statement

**Challenge**:

- Protecting multi-layer distributed systems, such as those found in enterprise systems against Multi-Stage Attacks (MSA).

**Issues**:

- **Attribution Problem** - Difficult to attribute a particular network flow to the corresponding client or attacker at the entry server due to mixing of multiple network flows at the intermediate servers.
- **Large Attack Surface** - Attack can start at any entry point and propagate in different paths.

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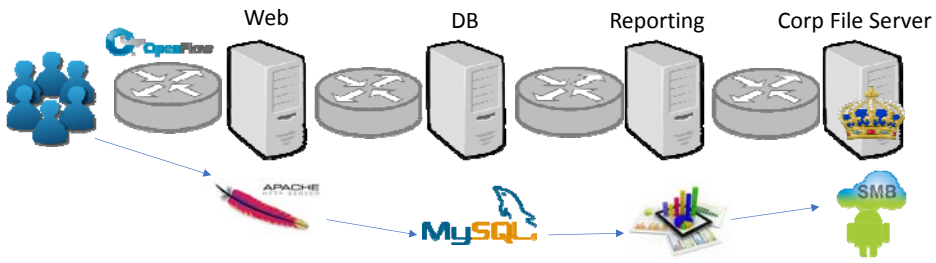
4

## Attribution Problem Illustration: Server Setup

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**Replication**

…



## Attribution Problem Illustration


**IDS Alert : Port Scan**
**{SA – Web Server IP, DA – DB Server IP}**

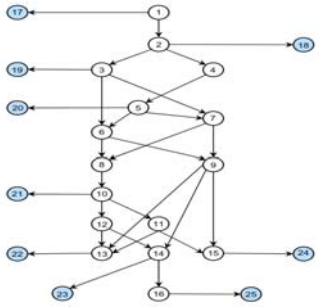
**PHP Command Injection**

**IDS Alert Generation**

**Attribution/ Un-Mixing/ Traceability Problem – Who is the attacker?**

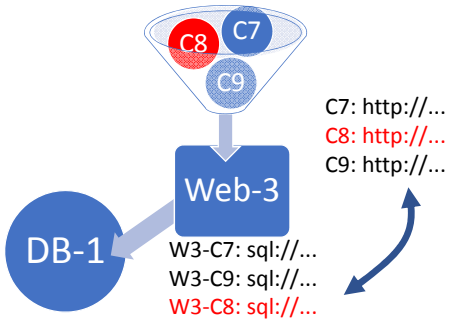
# Prior Work

**Attack Graph – Alert Inferencing [1]**



- **Disadvantage:**
  - Difficult to derive and to keep such information updated as systems are dynamic with new vulnerabilities being discovered and new users being added.

**Tagging [2]**

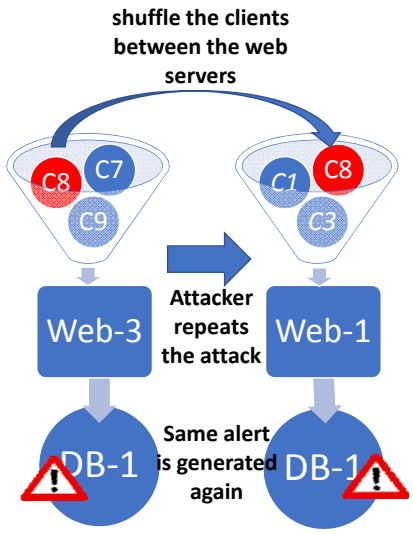



- **Disadvantage:**
  - Requires application level knowledge or deep packet inspection
  - computation and space overhead of carrying the tag along

[1] Modelo-Howard, Gaspar, Jevin Sweval, and Saurabh Bagchi. "Secure configuration of intrusion detection sensors for changing enterprise systems." *International Conference on Security and Privacy in Communication Systems*. Springer Berlin Heidelberg, 2011.
[2] Savage, Stefan, et al. "Practical network support for IP traceback." *ACM SIGCOMM Computer Communication Review*. Vol. 30. No. 4. ACM, 2000.



# Our Solution - TOPHAT

## Our Contribution

- TOPHAT can attribute multi stage attacks on a distributed system to a single external source, without relying on attack graphs or modifying server software.
- The MTD-style defense significantly increases the attacker's effort and can support identification of multiple attackers simultaneously.
- TOPHAT can support high availability for legitimate clients while identifying the attackers in the system.



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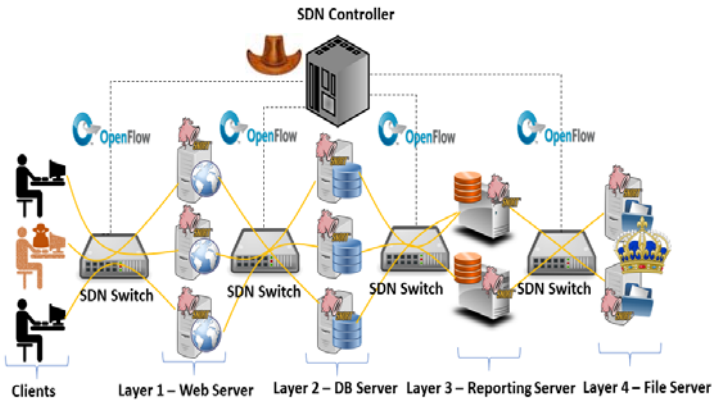
## System Model




- Each layer consists of multiple server instances or replica's for load balancing.
- Each layer is connected to the subsequent layers through open flow switches.
- SDN controller helps in dynamically routing the traffic to the desired server instances.
- Each server instance has an IDS installed.
- TOPHAT is installed in the SDN controller and is invoked whenever a strong alert is generated.



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# Attacker Model

- **Persistent Attacks –** The attacker repeats the attack until it proceeds to the next stage without an alert. Also, the predecessor stages in an attack must be repeated if the attacker is re-connected to a new server.
- **Strong Alerts –** The strong alert is an alert that with high certainty is known to be part of an attack (e.g., brute force attacks, known exploit signatures or other high priority* alerts). The attacker will generate at least one strong alert during a MSA.

*http://manual-snort-org.s3-website-us-east-1.amazonaws.com/node31.html#Snort_Default_Classifications - In Snort, rules are tagged with priority where "high" priority correlates with strong in our solution.

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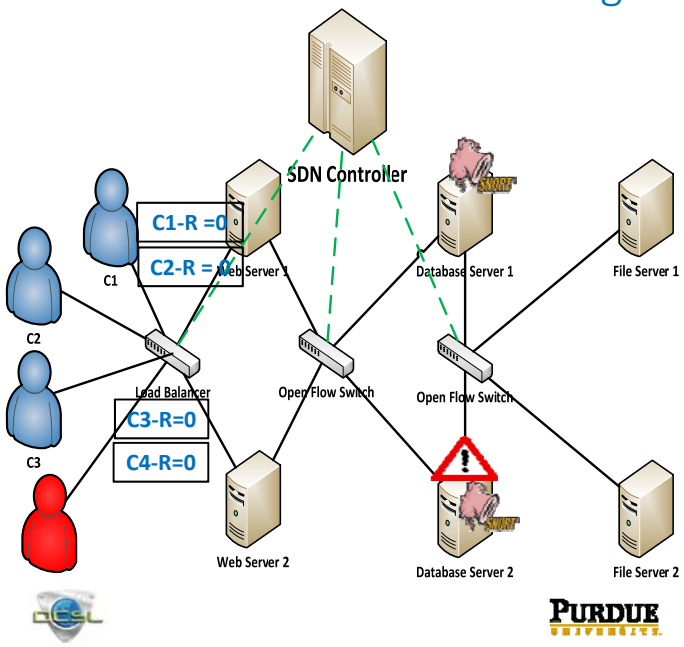
# TOPHAT Variant 1 - Uniform Assignment Algorithm




- Each client is associated with a risk factor that indicates the likelihood of the client being an attacker.
- The clients are tracked by the source IP address.
- Initially, all the clients have a risk factor of 0.
- The clients are allocated to the available web servers using uniform distribution.



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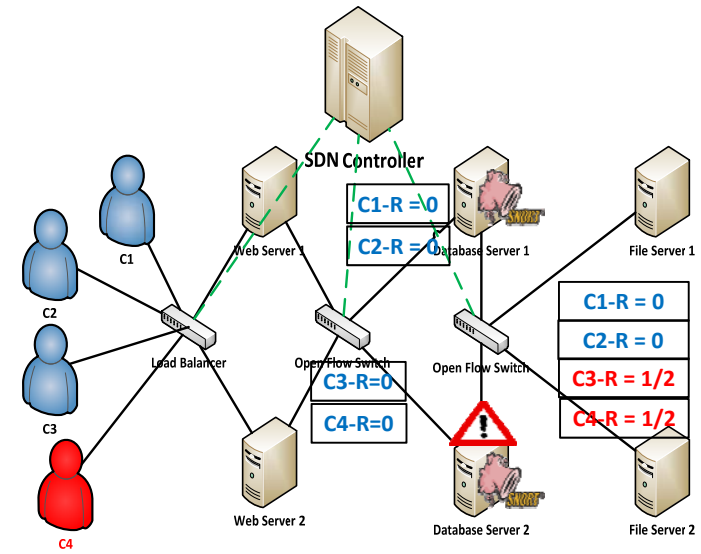
## TOPHAT Variant 1 - Uniform Assignment Algorithm




- When an alert is generated, uniform risk is assigned to all the clients present in the same server as the attacker.
- New Risk for each client = 1/ NCA (No. of clients allocated in the same server as the attacker).
- All the traffic is dropped by the open flow switch after the risk assignment.
- The clients including the attacker re-establish the connection.

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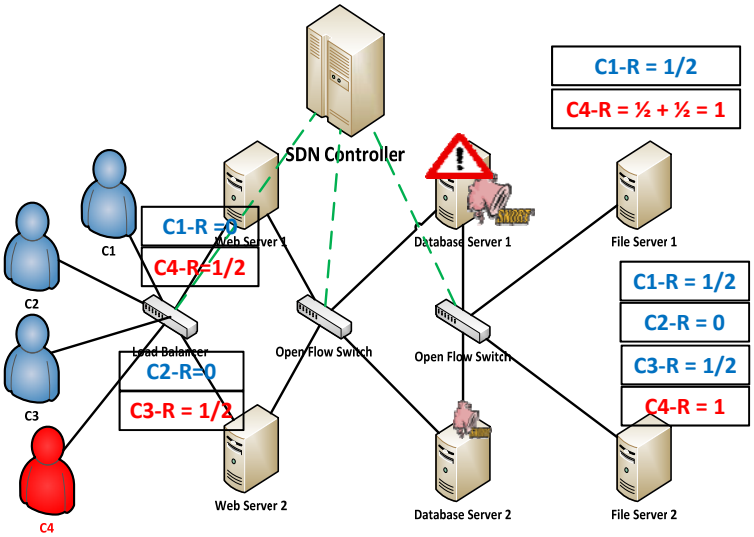
13

## TOPHAT Variant 1 - Uniform Assignment Algorithm




- Once again, the clients are shuffled between the available web servers.
- Now the risk factor of those clients allocated to the same server as the attacker are incremented by 1/NCA.
- After sufficient no. of repeated attacks, the attacker's risk will be maximum in the set without any possible ties.
- The attacker is isolated and his IP address is added to the blacklist.

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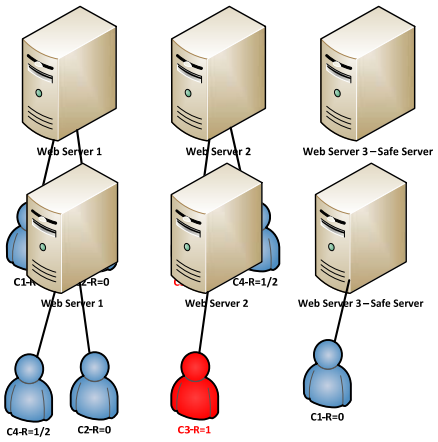
14

# TOPHAT Variant 2 - Low Risk Isolation Algorithm




- After each alert generation, 25% of lowest risk clients are moved to a safe server.
- The remaining clients are uniformly shuffled across the remaining processing servers.
- Each repeated attack reveals additional attacker information and increases the probability of the attacker to be identified.
- **Advantage:** The really well-behaved clients are not adversely affected at all.

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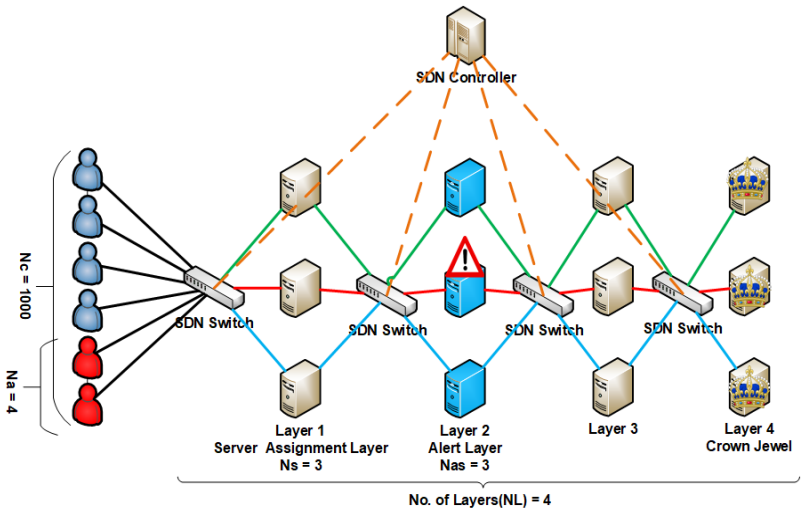
# Experiment Setup




- SDN environment is modeled using C++.

**Evaluation Parameters:**

- **Convergence Time:** Time at which single attacker or all attackers are identified.
- **Percentage of Failed Transactions (PFT(t)):** No. of client disruptions during attacker identification

$$PFT(t) = \frac{No.of\,Failed\,Transactions}{Total\,No.of\,Transactions}$$

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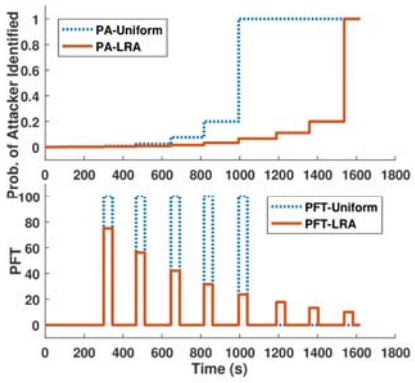
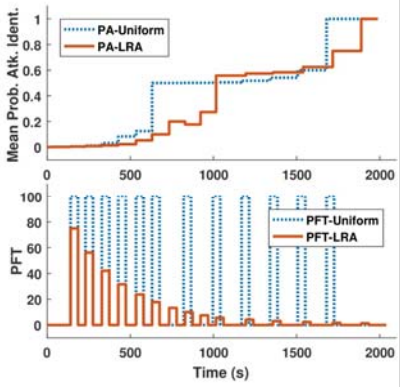
## Result : Convergence Over Time




Single Attacker




Four Attackers

- Uniform converges more quickly in both cases than the LRA as it has 3 servers to use for risk attribution while LRA reserves a server for the safe pool.
- Uniform has a constant PFT as all the clients are disconnected and re-assigned till the attacker is identified.
- LRA has a decaying PFT as only those clients remaining in active set are impacted for each attack.

**Faster Convergence vs Slower Convergence with better client access.**

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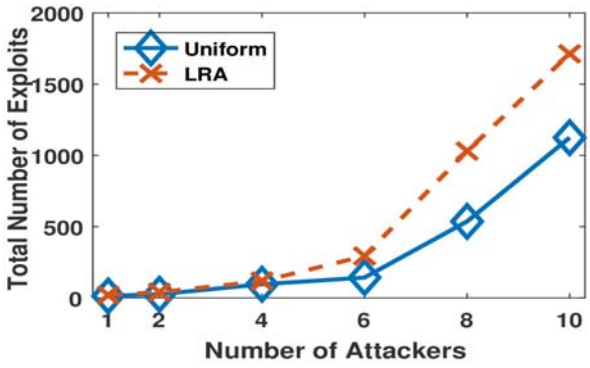
## Result: Attacker Effort




Total Effort for all attackers

- Attacker effort is measured using the number of times a server must be compromised at any layer by any attacker.
- Total number of exploits increases non-linearly with respect to number of attackers as many attackers will be reset even if they don't generate an alert themselves due to MTD.

**Note: Rest of the results can be found in the paper.**

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## Future Work

- Relaxing the assumption of strong alerts using more probabilistic risk assessment model that adapts the risk based on the quality of alerts.
- Optimize the number of IDS deployed to identify the attacker.
- Honey pot based discovery of the attacker after the isolation.

## Conclusion

- TOPHAT solves the problem of attributing an alert to an attacker in a multi-layered system.
- TOPHAT utilizes moving target defense (shuffling) to isolate the attacker.
- TOPHAT provides two algorithms namely Uniform for faster convergence and LRA for improving client connectivity during the attacks.
- TOPHAT also increases the attacker's effort by requiring multiple re-exploiting of the target system.

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19