SDNShield: Reconciliating Configurable Application Permissions for SDN App Markets

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Motivation

- SDN security concerns rank No.1 road blocker for SDN adoption*
- Over-privilege problem in control plane

* http://searchsdn.techtarget.com/feature/Five-reasons-IT-pros-are-not-ready-for-SDN-investment
Threat Models

- Exploit of existing benign-but-buggy apps
- Distribution of malicious apps by attacker
- Plenty of potential attacks
Approach

• Policy-based Access Control on Apps
  • Proactively eliminate apps’ over-privilege behaviors
Existing SDN Security Systems

- Cryptographic authentication
  - Mainstream controller platforms
  - No isolation

- Android-like permissions
  - SE-floodlight[NDSS15], FortNOX[HotSDN12]
  - Too coarse grain

- Strong & heavy isolation: Rosemary [CCS14]

- Open Question: how to have the developer and network admins collaborate to enforce security policies on apps?
Our Vision

• Flexible permission abstractions
  • App developers can express fine-grained permission requests.

• Limited increase on management burden
  • Administrators can easily refine app permissions with higher-level security policies.

• Reliable and lightweight enforcement
  • The controller needs a secure while efficient isolation architecture to enforce permissions.
Challenge

1. How to describe SDN app based permissions?
   • Accurately describe the complex API behavior space
   • Complicated logic is needed to depict inter-dimensional relations

SDNShield Permission Abstractions

2. How to reduce burden of admin on drafting security policy?
   • Need to reconcile inputs from app developer and network admin
   • Need a bridge to reshape app’s permission space with local security requirements

SDNShield Security Policy Reconciliation

3. How to reliably enforce permissions?
   • Runtime isolation
   • Reference monitoring

SDNShield Isolation Architecture
System Overview

• Permission Manifest
  • Describes per-app permission requirement
  • Written in permission language
  • Drafted by app developer
  • Reviewed by controller vendor

• Security Policy
  • Describes security requirements of local environment
  • Written in security policy language
  • Provided by network admin

Figure 4.2. SDNShield overview.
Roadmap

• SDNShield System Design
• SDNShield Implementation and Evaluations
  Published in HotSDN2013 and DSN2016

• Ongoing Extension to REST APIs and NFVs

• Conclusions
Permission Abstractions

```
PERM insert_flow LIMITING \nWILDCARD IP_DST 0.0.0.255 AND \n( FORWARD OR DROP )
```
Permission Abstractions

• Coarse-grained permission tokens
  • Describe chunks of logical resources
  • E.g., read_flow_table, insert_flow, visible_topology, send_pkt_out, etc.

• Fine-grained permission filters
  • Predicates on permission tokens connected with logic operators
  • Flow filters: flow match, flow action, flow wildcard, flow ownership
  • Topology filters: partitioning physical topology, virtual topology
  • Priority filter, statistics filter, event filter, etc.
Security Policy Reconciliation

• Goal: reduce administration burden on permission review

• Security Policy Language
  • Based on concepts that administrator are already familiar with
  • Three major abstractions:
    • Permission boundary
    • Mutual exclusion
    • Permission Customization

• Algorithm-assisted reconciliation process
  • Admin feeds customization conditions and local security policy
  • Reconciliation engine finds policy violation and provides permission candidates
Security Policy Examples

• Example 1:

```
ASSERT EITHER { PERM network_access } \ 
OR { PERM send_packet_out }
```

• \[\text{PERM visible_topology LIMITING LocalTopo}

```
PERM read_statistics
PERM network_access LIMITING AdminRange
PERM insert_flow
```

LET LocalTopo = \{SWITCH 0,1... LINK 3,4...\}
LET AdminRange = \{IP_DST 10.1.0.0 \ MASK 255.255.0.0\}

permission manifest  security policy
Isolation Architecture

• **Design Goals**
  • Execution and memory isolation
  • Mediating syscalls
  • Efficiency
  • No modification to Apps

• **Design Choices**
  • Thread-level isolation
  • Language-based reference monitoring (Java VM)
Implementation

• Platform-independent reconciliation engine and permission engine
  • Parses permission manifests and security policies
  • Library for efficient permission checking
  • 23k lines of code in Java

• Controller extensions
  • Implemented on OpenDaylight and Floodlight
  • Inter-thread communication and API wrapping
  • App initiation process
Evaluation

- Latency impact
  - Tested on two real apps
  - Almost unnoticeable latency difference

(a) L2 Learning Switch

(b) ALTO TE
Evaluation

• Throughput impact
Roadmap

• SDNShield System Design
• SDNShield Implementation and Evaluations
• Ongoing Extension to REST APIs and NFVs
• Conclusions
REST APIs

• REST (REpresentational State Transfer)
  • Resource-based: Each URI represents a resource.
  • Client-Server: Client connects to Server via HTTP protocol
  • HTTP verbs: POST-Create, GET-Select, PUT-Update, DELETE-Delete

• Benefits
  • Simple, flexible, unified, scalable

• Example

<table>
<thead>
<tr>
<th>HTTP</th>
<th>Verb</th>
<th>URI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>POST</td>
<td>/v2.0/routers</td>
<td>Create a router</td>
<td></td>
</tr>
<tr>
<td>DELETE</td>
<td>/v2.0/routers/{router_id}</td>
<td>Delete a router</td>
<td></td>
</tr>
<tr>
<td>GET</td>
<td>/v2.0/routers</td>
<td>Query all routers</td>
<td></td>
</tr>
</tbody>
</table>
Motivation in REST API Access Control

- Attacks outside controller remain
- Trusted Apps with certain privileges are still dangerous
- Hackers with access to trusted apps can attack underlay network
- Abstraction of SAL APIs makes Access Control easier
Design for REST API Access Control

Based on Mapping between REST APIs & SAL APIs
- REST API generally is an independent transaction
- A transaction contains several sequential primitive API calls
- REST API can be mapped into an API tree in time order

Data Center Scenario
"CreateNetwork" API

- ReadDataStore (Check if UUID exists)
- ReadDataStore (Check if tenant exists)
- WriteDataStore (Write tenant)
- ReadDataStore (Check if subnets exist)
- WriteDataStore (Write network)
- WriteFlow (Write network)
- UpdateDataStore (Update tenant)
NFV Scenarios

- Network functions are virtualized in cloud based platform.
- Controllers are responsible for leading traffic through a series of network functions, thus providing network services.
- NFVI providers can even provide controllers for tenants to manipulate their traffic on providers’ infrastructure.

More important role in network
But very limited security work done
Extending SDNShield to NFVs

- **App-Controller Interaction**
  - Multiple controllers locate in different layer, each with specific role
  - Cross-layer interactions between Apps and Controllers

- **SDNShield in NFV**
  - Controller is vital for NFV, (REST) interactions are frequent and complex
  - How to have efficient and effective access control for NFVs
Conclusions

- A novel and flexible permission control system for SDN applications
- Fine-grained permission abstractions
- Limited increase on administration burden

- Extending SDNShield to REST APIs and NFVs

http://list.cs.northwestern.edu/sdn
## Comparison

<table>
<thead>
<tr>
<th></th>
<th>Control-plane or Data-plane</th>
<th>Allow App Cooperation?</th>
<th>Protection beyond Flow Conflict</th>
<th>Protection beyond CP/DP Channel?</th>
</tr>
</thead>
<tbody>
<tr>
<td>FortNOX/FRESCO</td>
<td>CP</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>FlowVisor</td>
<td>CP</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>AvantGuard</td>
<td>DP</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>SDNShield</td>
<td>CP</td>
<td>Yes</td>
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