An OpenFlow Extension for the OMNeT++ INET Framework

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Motivation

Comparison of different controller architectures

Traditional switch design

OpenFlow design

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Outline

▶ OpenFlow background
  ▪ Basic principle and communication example

▶ OpenFlow simulation model
  ▪ Implemented nodes and messages

▶ Proof-of-concept evaluation
  ▪ Controller placement

▶ Summary and future work
OpenFlow Overview

- Basic principle
  - Separation of control- and data-plane
  - Open standard
  - Added as feature to commercial switches

- OpenFlow specifies a communication protocol between the data plane of a networking element and a remote control plane

- OpenFlow introduced by the McKeown group at Stanford University (2008)

- Since version 1.2 the standardization body for OpenFlow is the Open Networking Foundation (ONF)
Communication in OpenFlow Network

Controller

MAC table:

<table>
<thead>
<tr>
<th>MAC address</th>
<th>Ingress port</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Packet-in: unmatched frame with MAC 08-00-2A-0B-FE-FD

Src: 08-00-20-3A-00-4F
Dst: 08-00-2A-0B-FE-FD

Packet-out: flood on all ports except ingress port

Flow Table:

<table>
<thead>
<tr>
<th>Match Field</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>empty</td>
<td>empty</td>
</tr>
</tbody>
</table>

Host 1
MAC address 08-00-20-3A-00-4F

Host 2
MAC address 08-00-2A-0B-FE-FD

Host 1
MAC address 08-00-20-3A-00-4F

OpenFlow Switch

Flow Table:

<table>
<thead>
<tr>
<th>Match Field</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>empty</td>
<td>empty</td>
</tr>
</tbody>
</table>

Host 2
MAC address 08-00-2A-0B-FE-FD
Communication in OpenFlow Network

Flow-mod messages:

<table>
<thead>
<tr>
<th>Match</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Src: 08-00-2A-0B-FE-FD</td>
<td>Forward on port 1</td>
</tr>
<tr>
<td>Dst: 08-00-20-3A-00-4F</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Match</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Src: 08-00-20-3A-00-4F</td>
<td>Forward on port 2</td>
</tr>
<tr>
<td>Dst: 08-00-2A-0B-FE-FD</td>
<td></td>
</tr>
</tbody>
</table>

Packet-in: unmatched frame with MAC 08-00-20-3A-00-4F

MAC table:

<table>
<thead>
<tr>
<th>MAC address</th>
<th>Ingress port</th>
</tr>
</thead>
<tbody>
<tr>
<td>08-00-20-3A-00-4F</td>
<td>1</td>
</tr>
<tr>
<td>08-00-2A-0B-FE-FD</td>
<td></td>
</tr>
</tbody>
</table>

Packet-out: forward on port 1

Flow Table:

<table>
<thead>
<tr>
<th>Match Field</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Host 1
MAC address
08-00-20-3A-00-4F

OpenFlow Switch

Host 2
MAC address
08-00-2A-0B-FE-FD

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Overview Simulation Model

- Implementation background
  - Extends and requires INET framework version 2.0
  - Implementation according to OpenFlow specification 1.0
  - Based on OpenFlow header file

- Missing most important features of higher protocol versions
  - OpenFlow version 1.1
    - Multiple flow tables
    - Group actions
  - OpenFlow version 1.2
    - Extensible match support
  - OpenFlow version 1.3
    - Per flow meters
Implemented Messages

- Message types and message formats implemented according to OpenFlow specification
  - Establishment of OpenFlow channel
  - Asynchronous messages
  - Modify-state and packet-out messages

Diagram:
- Controller-to-Switch: OFP_Features_Request → OFP_Flow_Mod → OFP_Packet_Out
- Switch-to-Controller: OFP_Features_Reply → OFP_Packet_In
Implemented OpenFlow Nodes

- OpenFlow nodes
  - OpenFlow switch
  - OpenFlow controller
- Utility modules
  - Spanning tree module
OpenFlow Switch

- Communication with controller
- Handling of unmatched packets (Packet-In message to controller)
- Handling of controller-to-switch messages

- Store messages during controller request
- Management of flow entries

- Message processing on data plane
- Perform flow table lookups
- Notify switch application module about unmatched packets
- Store packets in buffer during controller request
OpenFlow Controller

- Communication with OpenFlow switch
- Sending Packet-Out messages
- Sending Flow Modification messages

Controller behavior:
- Placeholder module
- Implemented behavior:
  - Hub
  - Switch
  - Forwarding

Control plane:
- ofa_controller
- Signal Concept
- Hub
- Switch
- Forwarding

Components:
- notificationBoard
- interfaceTable
- routingTable
- namTrace
Controller Behavior

▶ Switch behavior
  ▪ Ordinary Ethernet switch

▶ Forwarding behavior
  ▪ Flow mod messages are sent to all switches on path between source and destination

Switch controller behavior

Forwarding controller behavior
Considered network
- Open Science, Scholarship, and Services Exchange (OS$^3$E)
- One of the first OpenFlow production deployments

Best controller location with respect to mean round-trip-time (RTT)?
Evaluation: Controller Placement

- Single Controller
  - Forwarding behavior
- Controller connected to all 34 OpenFlow switches
- Delay between the controller and a switch according to the data path delay

Performance Metric
- Mean RTT for each domain to all other domains
  - Host in each domain with ping app
  - Destination is chosen according to uniform distribution
Controller Placement Surface Plot

Switch and controller in same domain

Dense and well connected topology in the eastern part

Best controller locations:
- Chicago
- Indianapolis
- Louisville
- Nashville

Controller location index (see Table in Figure 7b)

Domain index (see Table in Figure 7b)
Controller Placement Boxplot

Best controller locations:
- Chicago
- Indianapolis
- Louisville
- Nashville

Location: Nashville
- Lowest median mean RTT

Location: Louisville
- Bit higher median but lower worst case mean RTT
Summary

- Implementation of OpenFlow in OMNeT++
  - Extends and requires INET framework version 2.0
  - Based on OpenFlow header file
  - Implementation according to OpenFlow specification 1.0

- Proof-of-concept evaluation
  - Best controller location for OS³E network
  - Only single controller architecture

- Future work
  - Implement and evaluate distributed controller architectures
  - Inter-controller communication
  - Resilience
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Thank You for Your Attention

Code available at
http://www3.informatik.uni-wuerzburg.de/research/ngn/openflow.shtml