Simulation-based Evaluation of a Synchronous Transaction Model for Time-Sensitive Software-Defined Networks

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Introduction
## Time Sensitive Networking

- Designed for industrial control equipment and vehicle communication networks
- Defined in IEEE 802.1Q
- Supports ethernet in real-time environments through time synchronization and traffic prioritization
- Bases on Ethernet frames with Q-Tag holding a VLAN ID and priority code point

### Table

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Destination MAC</th>
<th>Source MAC</th>
<th>Ether Type</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8</td>
<td>1 2 3 4 5 6</td>
<td>1 2 3 4 5 6</td>
<td>1 2</td>
<td>. . n</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Preamble</th>
<th>Destination MAC</th>
<th>Source MAC</th>
<th>802.1Q-Header</th>
<th>Ether Type</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8</td>
<td>1 2 3 4 5 6</td>
<td>1 2 3 4 5 6</td>
<td>1 2 3 4</td>
<td>1 2</td>
<td>. . n</td>
</tr>
</tbody>
</table>
Each port has a frame selector instance to control the forwarding of packets according to QOS guarantees.
Different transmission selection algorithms can be used.
State changes of gates can be timed using a Gate Control List.
Time Sensitive Networking
Gate Control List (GCL)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Time Slot</th>
<th>Time t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>n</td>
<td></td>
<td>n+1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Priority</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time t</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>

Gate state
C = Closed
o = Open
Software-Defined Networking
Software-Defined Networking

Control Plane

Data Plane

Switch
Switch
Switch
Router

secVI
Software-Defined Networking

- Control Plane
  - SDN Controller

- Data Plane
  - Switch
  - Switch
  - Switch
  - Router
Transactions

A
Atomicity

C
Consistency

I
Isolation

D
Durability
Concept
Overview

Four Phases

- Lock
- Reconfigure
- Commit
- Unlock
Example

**Lock**
- MAC-Address is used for ordering

**Reconfigure**
- Instantiate copy of running configuration
- Lock candidate configuration
- Apply reconfigurations to candidate configuration

**Commit**
- All devices are synchronized
- Commit execution timestamp is based on worst-case execution time of commit phase

**Unlock**
- All acquired locks will be unlocked
Evaluation
Simulation Environment

SDN4CoRE
NetConf / TSN + SDN

CoRE4INET
IEEE 802.1Q / TSN / AVB / A56802

INET framework 3.x
Ethernet / Internet Protocol / TCP / UDP

OMNeT++ 5.5.1
Discrete Event Simulator

https://github.com/CoRE-RG/SDN4CoRE
Evaluation Network

Network Details

- On all devices a TDMA schedule is used repeating every 1 ms
- Traffic at the nodes is started sequentially with an offset of 100 ms
- All traffic sources send one full sized Ethernet-frame every millisecond
- All packets share the same priority
- For each node two modifications are needed
  1. Add the new flow to switches flowtable
  2. Update GCL schedule on switches
Non-Transactional Configurations

Configurations Real-Time Flow 1
Configurations Real-Time Flow 2
Configurations Real-Time Flow 3

End-to-end latency [ms]

Simulation time [s]

Real-Time Flow 1
Real-Time Flow 2
Real-Time Flow 3
Non-Transactional Configurations

Configurations Real-Time Flow 2

Flow Table  GCL

End-to-end latency [ms]

Simulation time [s]

Real-Time Flow 1
Real-Time Flow 2
Time-Synchronous Transactions

Transaction Real-Time Flow 1
Transaction Real-Time Flow 2
Transaction Real-Time Flow 3

End-to-end latency [ms]

Simulation time [s]
Conclusions & Outlook

- **Non-transactional reconfiguration**
  - May lead to inconsistencies causing increased latencies
    - Not suitable for time critical traffic

- **Time-synchronous transactions**
  - Don't affect latencies of real-time traffic
    - Suitable for time critical traffic

- **Future Work**
  - Investigate performance under various forms of modifications
  - Compare different forms of commit synchronization
Many thanks for your interest and attention.

We’ll be looking forward to your questions