Network Scheduling in Software-defined Environments

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Outline

• Background
• Use cases
• Accurate scheduling
• Conclusion
The TimedSDN Project
Software Defined & Programmable Networks

- Centralized
- Flexible
- Dynamic
Timed SDN at a Glance

A protocol allowing the controller to schedule network updates

Synchronized clocks
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Using Time in Network-managed Environments

Coordinated Configuration Update

Coordinated Snapshot
Using **Time** to Coordinate **Path** Updates

Simultaneous
Switches invoke update at the same time

Timed sequence
Switches invoke update according to a scheduled sequence

- OpenFlow
- I2RS
Time is Optimal for Flow Swaps [INFOCOM ‘16]

A key benefit of SDN:
Dynamic path allocation based on network load
Time is Optimal for Flow Swaps  [INFOCOM ‘16]

A key benefit of SDN: Dynamic path allocation based on network load

If $O_1, O_2$ are not updated at the same time...

Temporary congestion.

$O_2$ is updated first.

old
new
Time is Optimal for Flow Swaps [INFOCOM ‘16]

A key benefit of SDN: Dynamic path allocation based on network load

If $O_1$, $O_2$ are updated at the same time: No congestion!
Consistent Path Update

0. The ‘before’ configuration.
1. Controller updates $S_1$.
2. Controller updates $S_2$.
3. Controller updates $S_3$. 

The TimedSDN Project
Simultaneous Updates?

En-route packets run into a ‘black hole’. Not consistent!
Timed Multi-phase Consistent Updates [SOSR ‘15]

- The controller sends timed update messages to $S_1$, $S_2$, $S_3$.
- Scheduled updates occur at times $T_1$, $T_2$, $T_3$.

Controller does not need to wait between steps!
Using **Timestamps** instead of **Time** [SWFAN ‘16]

Timestamp can be used in processing of intermediate devices.

- Delay measurement.
- Policy / path decision criterion: “Do action A if Timestamp≥T₀”

Timestamp is
- Pushed by ingress switch.
- Removed by egress switch.
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Accurate Synchronization: It’s Already Here

Precision Time Protocol (PTP)
[IEEE 1588 2008]
~1μsec accuracy

Mobile backhaul
Power substations
Industrial automation
Financial applications

China Mobile: over 1,000,000 PTP-enabled base stations
https://mailarchive.ietf.org/arch/attach/tictoc/pdfsY1ADO.pdf
**TIMEFLIP**: Timestamp-based TCAM Lookup

A Timestamp is attached to packet’s metadata by the switch

**conventional**

Network Device

TCAM

$S_{W}, ..., S_{1}$

packet’s search key

action

**TimeFlip**

Network Device

TCAM

packet’s search key

action

The timestamp is used in the TCAM key – time range.

COTS switches can synchronize clocks very accurately ~ 1 μsec.
[Using IEEE 1588 Precision Time Protocol (PTP) or GPS]
The Cost of TIMEFLIP: 1 Bit / 1 Entry

• **Theorem:** if \( TOL \geq 2^{\lceil \log_2 (\Delta) \rceil} \), then the every timestamp range requires as little as:
  – 1 bit in the timestamp field.
  – 1 TCAM entry.
TIMEFLIP: Would it Work on a Real Switch?

Yes !!

Microbenchmark: TimeFlip was tested on a Marvell 98DX4251 with a sub-microsecond accuracy.
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The TimedSDN Project

Why do we need time in SDN?

- Scheduling protocols
- Accurate scheduling methods
- SDN Clock synchronization

Flow Swaps
TIME4
[INFOCOM, ‘16]

Multi-phase
updates
[SOSR, ‘15]

Data Plane
Timestamping
[SWFAN, ‘16]

Network-managed
coordination
[NOMS, ‘16]

OpenFlow
Scheduled Bundles
[INFOCOM ’16]

NETCONF
Time Capability
[NOMS ’16]

TIMEFlip
[INFOCOM ‘15]

ONEClock
[NOMS ‘16]

REVERSEPTP
[HotSDN ‘14, ISPCS ‘14]
The TimedSDN Project – Practical Aspects

Scheduling protocols

- OpenFlow Scheduled Bundles
  [INFOCOM ’16]

- NETCONF Time Capability
  [NOMS ’16]

Published!

- OpenFlow 1.5
- RFC 7758
The **TimedSDN** Project – Practical Aspects

Open Source Prototypes

- OpenFlow Scheduled Bundles
- NETCONF Time Capability
- ReversePTP

[https://github.com/TimedSDN](https://github.com/TimedSDN)
Timed SDN at a Glance

- A protocol allowing the controller to schedule network updates
- Synchronized clocks

Controller

Switches
The TimedSDN Project – Future Directions

- Timed Updates
- Data plane timestamping
- Time as a network programming abstraction
- Implementation and wide-scale experiments

- NETCONF
  RFC 7758 ++
- I2RS
- SFC
  [link](https://tools.ietf.org/html/draft-browne-sfc-nsh-timestamp-01)
- NVO3
- P4

We would be happy to collaborate with vendors / operators who are interested!
Thanks!

The TimedSDN Project
http://tx.technion.ac.il/~dew/TimedSDN.html
A Closer Look at TIMEFLIP

Further details can be found in:
• TimeFlip paper (http://tx.technion.ac.il/~dew/TimeFlipINFOCOM.pdf)
• TimeFlip presentation (http://tx.technion.ac.il/~dew/TimeFlipInfocomPres.pdf)
• Next few slides...
SDN Switches

controller

switch

switch

switch

switch

Switch

incoming packet

TCAM\(_1\)

TCAM\(_2\)

\ldots

TCAM\(_n\)

outgoing packet
TCAM: Ternary Content Addressable Memory

- Memory for quick searching

- Top-down search: first match “wins”

- Ternary: 0 / 1 / *

- * = don’t care
**TIMEFLIP**: Timestamp-based TCAM Lookup

A Timestamp is attached to packet’s metadata by the switch

**conventional**

**TimeFlip**

The timestamp is used in the TCAM key – time range.

COTS switches can synchronize clocks very accurately ~ 1 μsec. [Using IEEE 1588 Precision Time Protocol (PTP) or GPS]

The TimedSDN Project
Time-based Updates using TIMEFLIP

TimeFlip: switch accurately starts using ‘new’ at $T_0$.

Network Device

TCAM

search key

old
new

controller

The TimedSDN Project
Example: Timestamp Format

<table>
<thead>
<tr>
<th>Time.Sec</th>
<th>Time.Frac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seconds</td>
<td>Second Fraction</td>
</tr>
</tbody>
</table>
Example: TIMEFLIP in Practice

Goal: schedule an update to be performed at 2016-07-22 11:41:11 (at the beginning of the second)

Procedure: (steps also appear in the figure)
Step 1: install a TimeFlip with ‘1’ in the lsbit of the seconds field, and ‘don’t care’ in the rest.
Step 2: the update becomes effective exactly at the turn of the second.
Step 3: make the TCAM rule permanent by writing ‘don’t care’ to the lsbit of the timestamp field.
References


