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MILANO 1863

openstate.p4
Supporting Stateful Forwarding in P4

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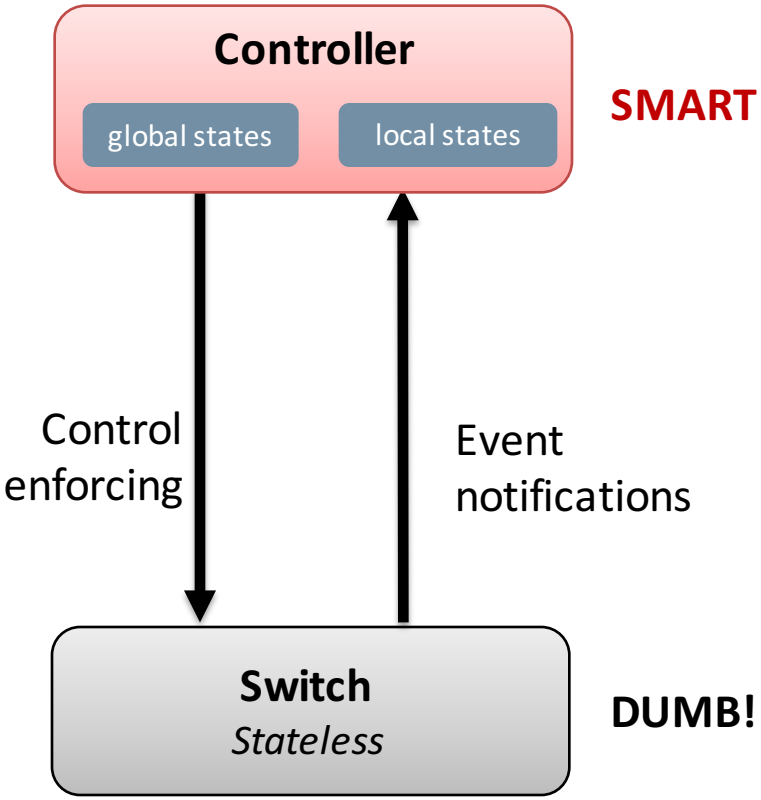
Stateless dataplane

Stateless model (e.g. OpenFlow)



SMART!

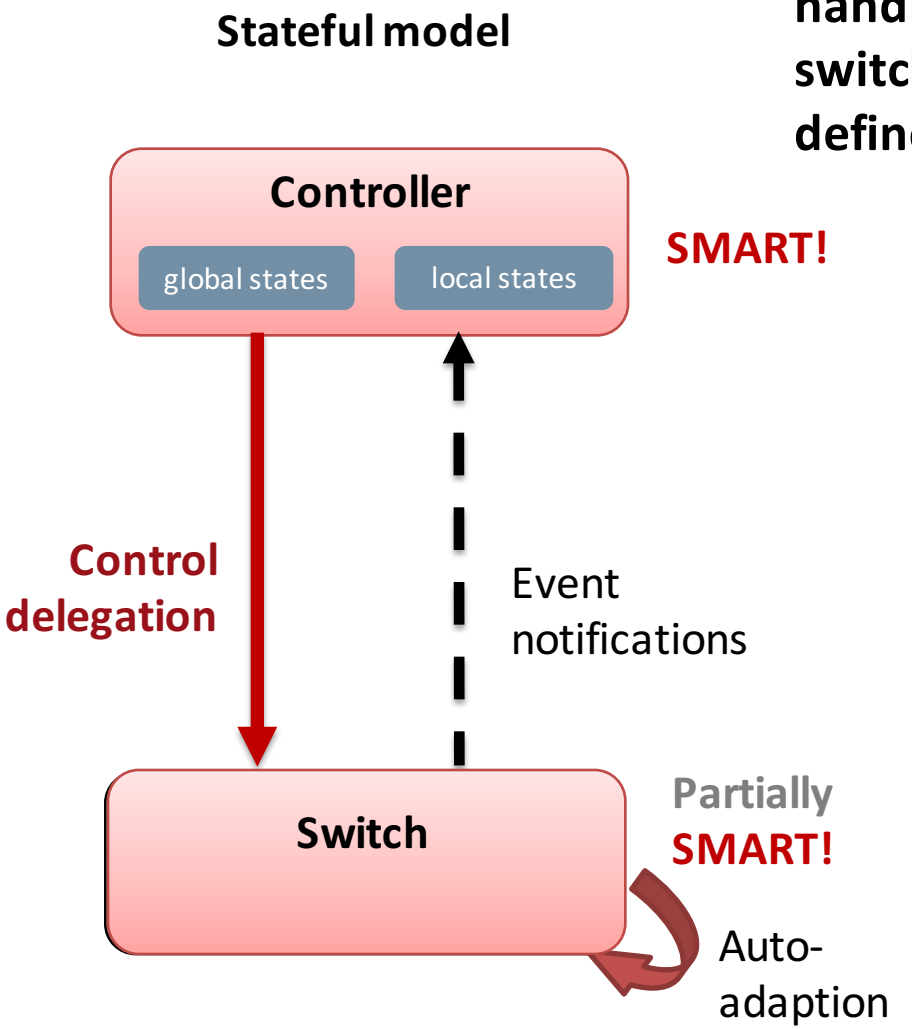
DUMB!

SDN applications dynamically adapt forwarding rules based on network states, either global and local

Event notifications:
- Packet arrivals
- Topology changes
- Traffic statistics

Control:
- Add rules
- Modify rules
- Delete rules
- Query statistics
- Send packets

Stateful dataplane



The idea of a stateful dataplane is to handle local states directly in the switches based on different sets of rules defined by the controller

Control delegation:

- Definition local states
- Definition of a "behavioral forwarding" (set of rules) per state
- Definition of "event" for state transitions

(state machine)

Event notifications:

- Notifications of event relevant for global states
- Local states synchronization (if needed)

Advantages and limitations

- In some network scenarios the control path to the controller is too slow for ensuring quick reaction to events
  - 1s delay in link failure reaction = 10M packets lost @ 100 Gbps
- And the signaling overhead generated quite large

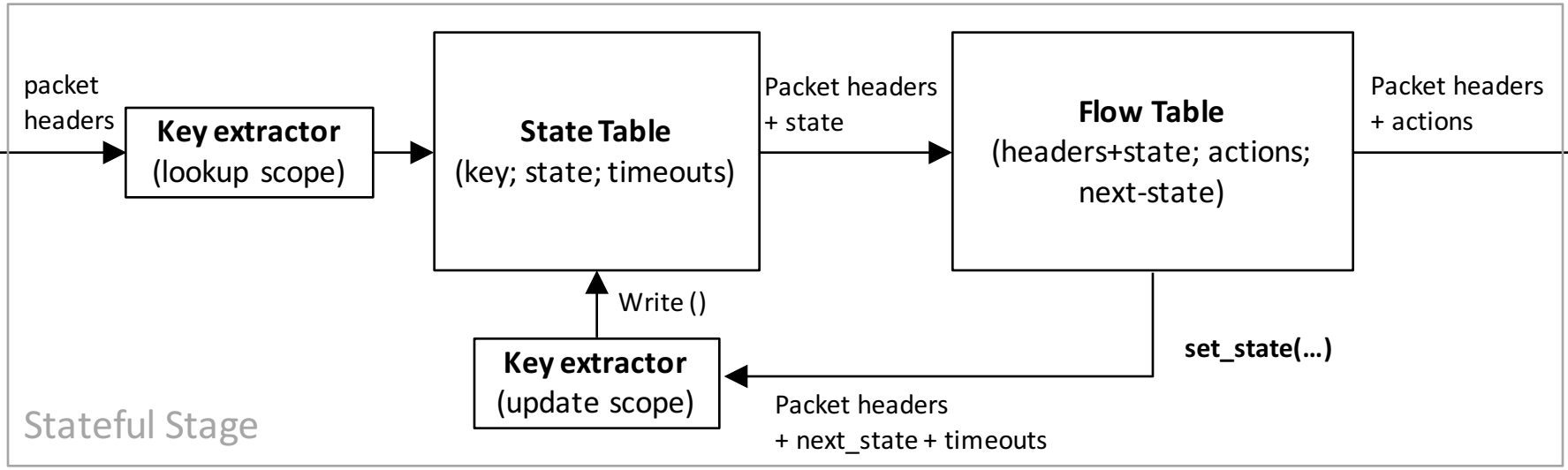
Quick local reaction

Low signaling overhead

- The set of supported local events must be compatible with the standard capabilities of a switch (header matches, timers, meters, …) – extensions for new gen hw
- State transitions must be implementable in a efficient way on hardware platforms (and high performance soft switches)

Not all state machines can be supported

How: OpenState architecture



Ingredients:

- new **set_state action**
- **lookup and update scope** as keys extracted from header (they may be different (cross flow state transitions)
- **state table** used for per-flow state information retrieval (easily implementable as a hash table) – [entries = # flows]
- **state machine** execution in a flow table – [entries = # states]

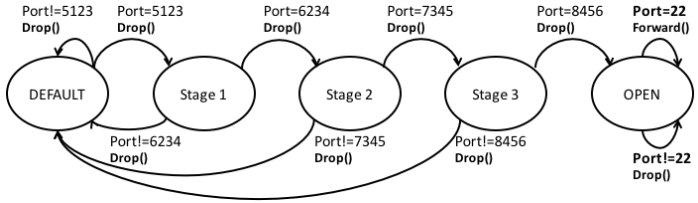
Abstraction:

- Mealy state machine $(\mathrm{T}: I \times S \rightarrow O \times S)$

[CCR14] G. Bianchi, M. Bonola, A. Capone, and C. Cascone, *"OpenState: Programming Platform-independent Stateful OpenFlow Applications Inside the Switch"* ACM SIGCOMM Computer Communication Review, vol. 44, no. 2, pp. 44–51, 2014.

Toy example: Port knocking firewall

Drop all packets from an IP source until a sequence of packets with a given ("secret") sequence of port numbers is received; then open port 22.



1) State lookup

IPsrc=1.2.3.4	Port=8456

2) State transition

STAGE-3	IPsrc=1.2.3.4	Port=8456

State Table

Flow key	state
IPsrc= … …	… … …
Ipsrc= … …	… … …
IPsrc=1.2.3.4	Write: OPEN
IPsrc=5.6.7.8	OPEN
IPsrc= … …	… … …
IPsrc= no match	DEFAULT

Flow Table

Match fields		Actions	
state	headers	action	Next-state
DEFAULT	Port=5123	drop	STAGE-1
STAGE-1	Port=6234	drop	STAGE-2
STAGE-2	Port=7345	drop	STAGE-3
STAGE-3	Port=8456	drop	OPEN
OPEN	Port=22	forward	OPEN
OPEN	Port=*	drop	OPEN
*	Port=*	drop	DEFAULT

write

3) State update

OPEN

IPsrc=1.2.3.4	Port=8456

Work so far

Based on OpenState basic abstraction we have put together a European H2020 research project to prove its feasibility and extend it to more general stateful dataplane abstractions

www.beba-project.eu

Proof-of-concept [OS][HPSR15]:

- SW implementation:
  - based on CPqD softswitch
- HW implementation:
  - based on FPGA

Applications [EWSDN15][DRCN15]:

- MAC learning
- Label/address advertisement learning
- Flow-consistent Load Balancing
- Denial-of-Service mitigation
- **Failure detection & recovery**
- **…**

Come and see our demo!

[OS] http://openstate-sdn.org - public repository with openstate implementation and example applications (on mininet)

[HPSR15] S. Pontarelli, M. Bonola, G. Bianchi, A. Capone, C. Cascone, "Stateful Openflow: Hardware Proof of Concept", IEEE HPSR 2015, Budapest, July 1-4, 2015

[EWSDN15] C. Cascone, L. Pollini, D. Sanvito, A. Capone, "Traffic Management Applications for Stateful SDN Data Plane", EWSDN 2015 (4th European Workshop on Software Defined Networks) , Bilbao, Sept. 30-Oct 2, 2015,

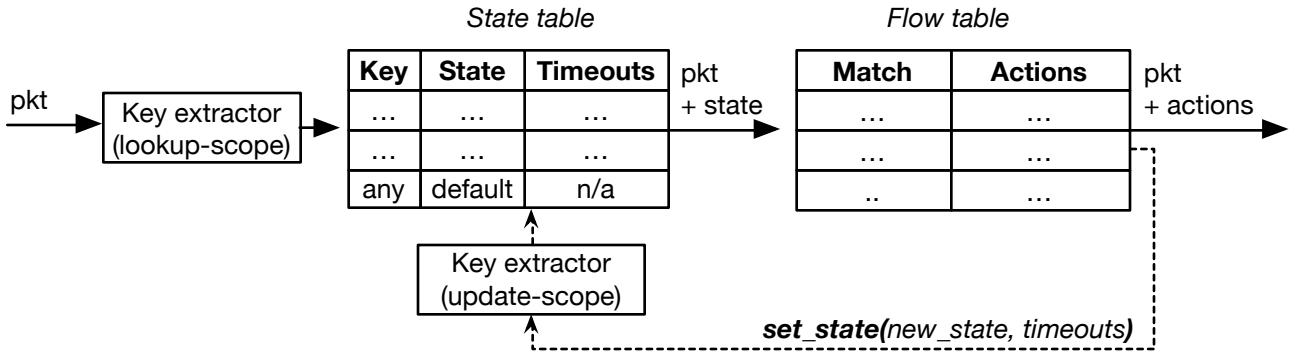
[DRCN15] A. Capone, C. Cascone, A.Q.T. Nguyen, B. Sansò, "Detour Planning for Fast and Reliable Failure Recovery in SDN with OpenState", IEEE DRCN 2015, Kansas City, USA, March 24-27, 2015.

OpenState & P4

- With the experience acquired in analyzing opportunities and limitations of stateful dataplanes it was quite natural to attempt the implementation of OpenState in P4
- It turned out that it is actually possible to use P4 to describe an OpenState stateful stage
- However:
  - The workarounds we have used point out possible improvements in P4 for the support of stateful dataplanes
  - Some open questions remain on the level of flexibility that is reasonable assuming for the target

Goal: #include “openstate.p4”

OpenState abstraction



What we need:

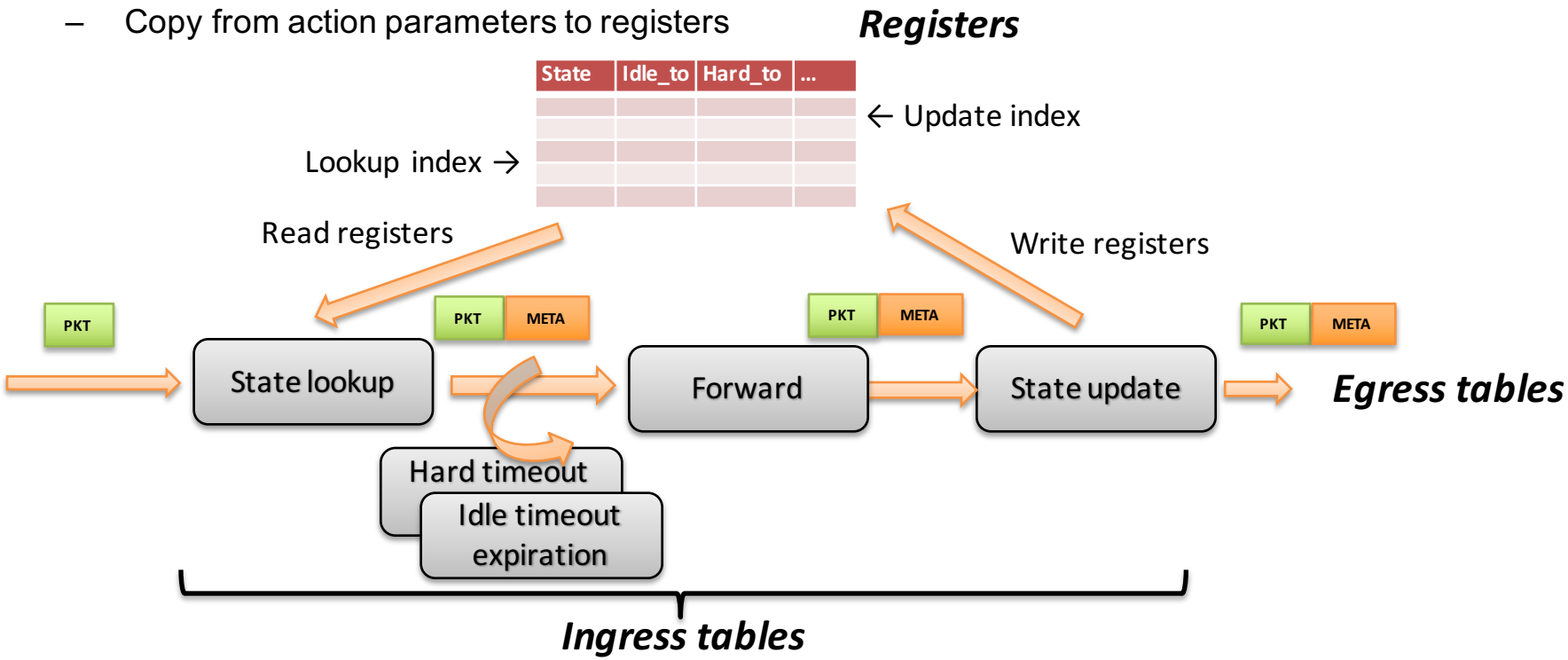
1. State table
2. Key extractors (lookup/update)
3. State idle/hard timeout handling
4. Set-state action

What we have (P4 abstractions):

1. Registers (stateful memories)
2. Hash generators
3. Packet ingress timestamp
4. Primitive actions (read/write registers)

Control flow at a glance

1. **State lookup**
   - hash generator produce a index to access registers
   - copy from registers to packet metadata
2. **Timeouts handling** at control flow
3. **User-defined forwarding logic**
4. **State update** (state transitions defined by user)
   - Update index might be different from lookup
   - Copy from action parameters to registers



openstate.p4

State table

Requirement:

- store flow states, possibly a very large number

Our workaround:

- registers (one for each column of the state table)

Issues:

- addressing constrained by register size

Ideal abstraction:

- state table as a dedicated table type
- exact match on 1 field, a “flow key” of arbitrary length
- only 1 action that writes metadata (state, timeouts, etc.)
- **need data plane driven insert/update**
  (i.e. OVS “learn” action)

openstate.p4

Key extractors (lookup / update)

Requirement:

- uniquely access state entries, optionally different in lookup/update operations
  Cross-flow state handling (e.g. MAC learning)

Our workaround:

- hash generators on different field lists

Issues:

- collisions → state inconsistency

Ideal abstraction:

1. programmable hash generators
2. simple fields concatenation

openstate.p4

```
field_list_calculation lookup_hash {
    input {
        lookup_scope;
    }
    algorithm : crc32;
    output_width : 32;
}

field_list_calculation update_hash {
    input {
        update_scope;
    }
    algorithm : crc32;
    output_width : 32;
}
```

maclearning.p4

```
field_list lookup_scope {
    ethernet.dstAddr;
}

field_list update_scope {
    ethernet.srcAddr;
}
```

openstate.p4

State timeouts

Requirement:

- enable time-based state transitions
  i.e. OpenFlow-like idle/hard state timeouts

Our workaround:

- timestamp comparison at control flow
  E.g.
```
if (ingress_timestamp > idle_exp_timestamp)
        apply(idle_to_expiration) …
```

Issues:

- expired registers not flushed

Ideal abstraction:

- support for transparent timeout handling in the state table
- expose target timestamp resolution (ms, µs, ns, etc.)
  Short timeouts critical for applications like failure detection, Denial-of-Service mitigation, etc.

Conclusions

- Shown feasibility in P4 of a stateful data plane abstraction like OpenState
- openstate.p4 is based on a number of workarounds
- Room for improvements in P4 specification
- E.g. we need support for a proper state table !

Download & try:

http://github.com/OpenState-SDN/openstate.p4

http://www.openstate-sdn.org