Open Networking Foundation

Performance evaluation of ONOS support for P4Runtime

Proposed activity for the Sec&Perf brigade

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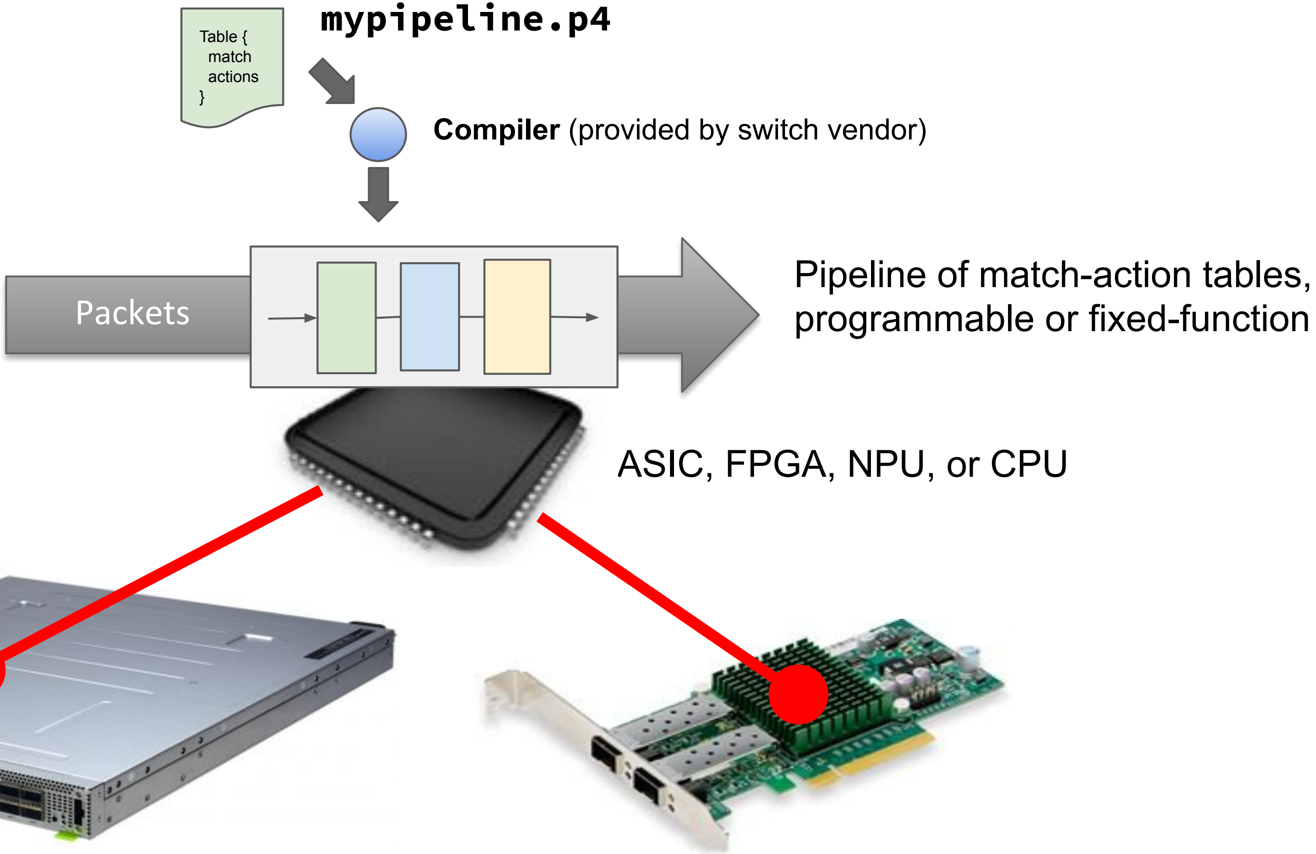
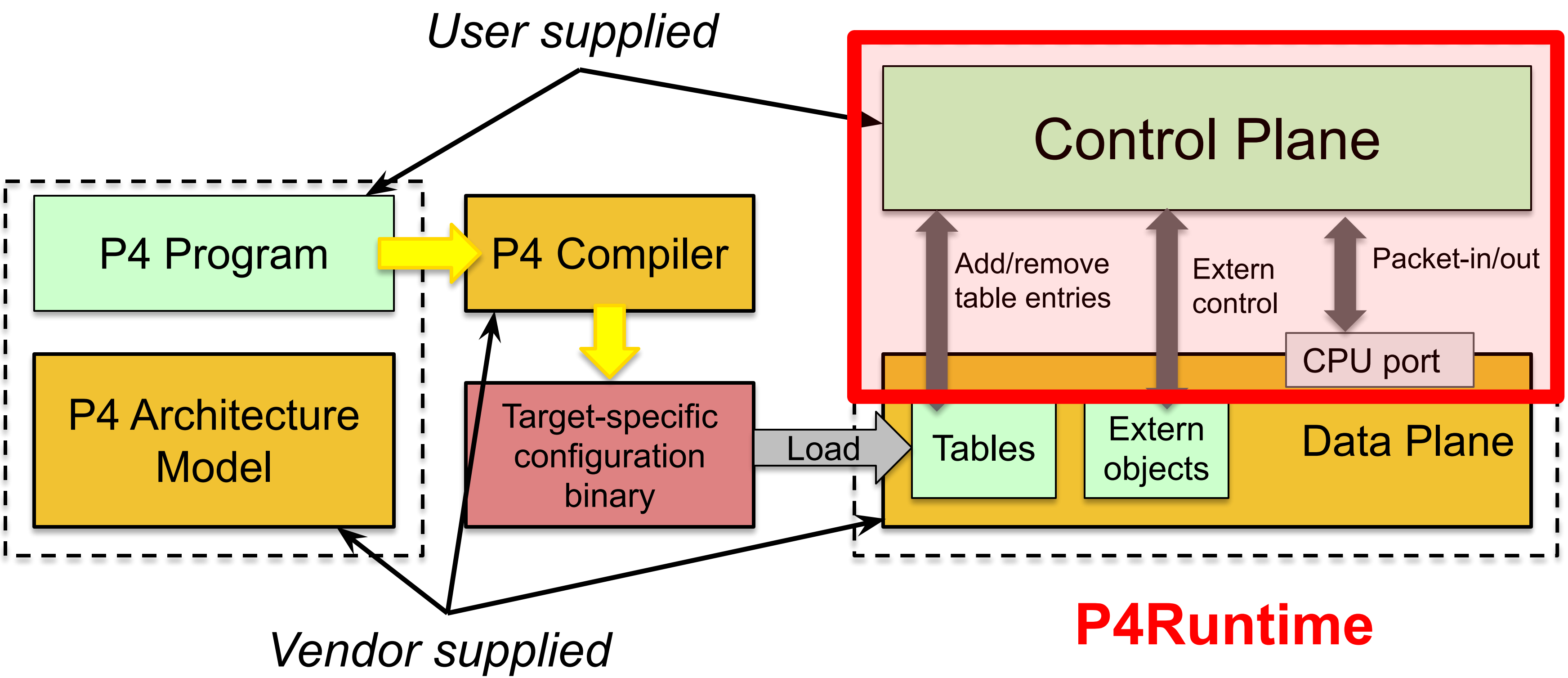
Outline

- P4Runtime recap
- P4Runtime subsystem in ONOS
- Performance considerations

P4 - Data plane pipeline programming language



P4 workflow summary



Slide courtesy P4.org

P4Runtime v1.0

- **Released on Jan 2019**
- **Open source specification**
  - Started by Google and Barefoot in mid-2016
  - Contributions by many industry professionals
- **Based on continuous implementation feedbacks from Google and ONF**
  - First ONF demo in Oct 2017

https://p4.org/p4-spec/
https://github.com/p4lang/p4runtime

P4Runtime Specification

version 1.0.0

The P4.org API Working Group

2019-01-29

Abstract

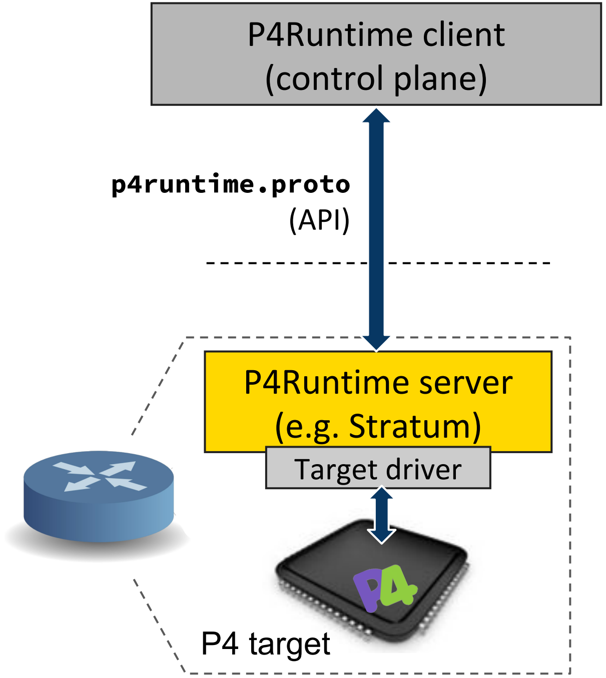
P4 is a language for programming the data plane of network devices. The P4Runtime API is a control plane specification for controlling the data plane elements of a device defined or described by a P4 program. This document provides a precise definition of the P4Runtime API. The target audience for this document includes developers who want to write controller applications for P4 devices or switches.

Contents

1

P4Runtime overview

- **Protobuf-based API definition**
    - Efficient wire format
    - Automatically generate code to serialize/deserialize messages for many languages
- **gRPC-based transport**
    - Automatically generate high-performance client/server stubs in many languages
    - Pluggable authentication and security
    - Bi-directional stream channels
- **P4-program independent**
    - Allow pushing new P4 programs to reconfigure the pipeline at runtime
- **Equally good for remote or local control plane**
    - With or without gRPC



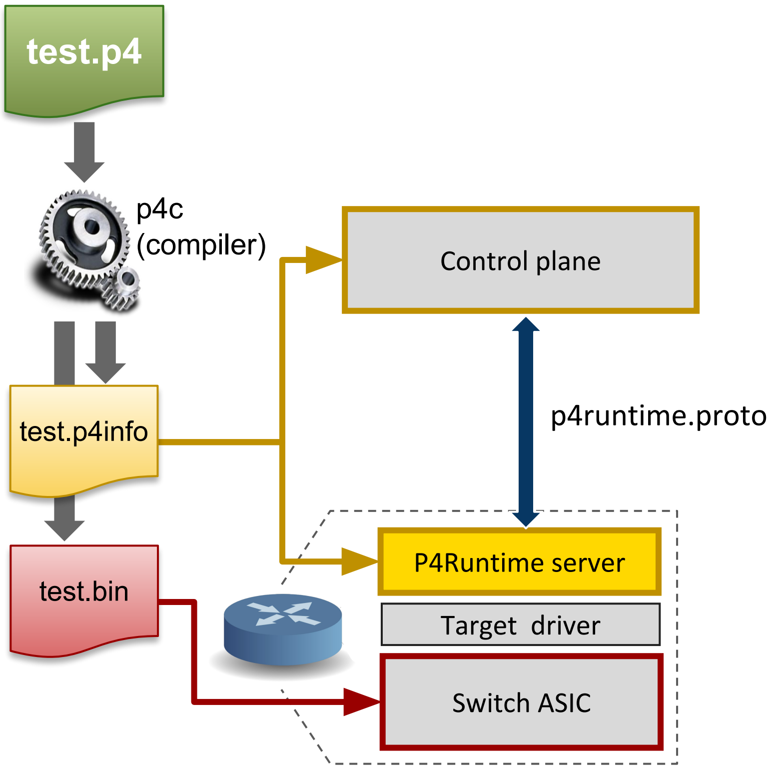
P4Runtime main features

- **Batched read/write of pipeline state**
  - Table entries, action groups, counters, registers, etc.
- **More robust mastership handling wrt OpenFlow**
  - With ordering of writes
- **Multiple master controllers via role partitioning**
  - E.g. local control plane for L2, remote one for L3
- **More flexible and efficient packet I/O**
  - OpenFlow-like packet-in/out with arbitrary metadata
  - Digests, i.e. batched notification to controller with subset of packet headers
- **Designed around PSA architecture**
  - But can be extended to others via Protobuf “Any” messages

P4 compiler outputs

1. **Target-specific binaries**
   - Used to realize switch pipeline
     (e.g. binary config for ASIC, bitstream for FPGA, etc.)

2. **P4Info file**
   - “Schema” of pipeline for runtime control
     - Captures P4 program attributes such as tables, actions, parameters, etc.
   - Protobuf-based format
   - Target-independent compiler output
     - Same P4Info for SW switch, ASIC, etc.



Full P4Info protobuf specification:
https://github.com/p4lang/p4runtime/blob/master/proto/p4/config/v1/p4info.proto

P4Info example

basic_router.p4

```
...

action ipv4_forward(bit<48> dstAddr,
                    bit<9> port) {
   eth.dstAddr = dstAddr;
   metadata.egress_spec = port;
   ipv4.ttl = ipv4.ttl - 1;
}

...

table ipv4_lpm {
   key = {
       hdr.ipv4.dstAddr: lpm;
   }
   actions = {
       ipv4_forward;
       ...
   }
   ...
}
```

P4 compiler

basic_router.p4info

```
actions {
  id: 16786453
  name: "ipv4_forward"
  params {
    id: 1
    name: "dstAddr"
    bitwidth: 48
    ...
    id: 2
    name: "port"
    bitwidth: 9
  }
}
...
tables {
  id: 33581985
  name: "ipv4_lpm"
  match_fields {
    id: 1
    name: "hdr.ipv4.dstAddr"
    bitwidth: 32
    match_type: LPM
  }
  action_ref_id: 16786453
}
```

P4Runtime table entry WriteRequest example

basic_router.p4

```
action ipv4_forward(bit<48> dstAddr,
                    bit<9>  port) {
   /* Action implementation */
}
table ipv4_lpm {
   key = {
       hdr.ipv4.dstAddr: lpm;
   }
   actions = {
       ipv4_forward;
       ...
   }
   ...
}
```

Logical view of table entry

```
hdr.ipv4.dstAddr=10.0.1.1/32
     -> ipv4_forward(00:00:00:00:00:10, 7)
```

Control plane generates

WriteRequest message (protobuf text format)

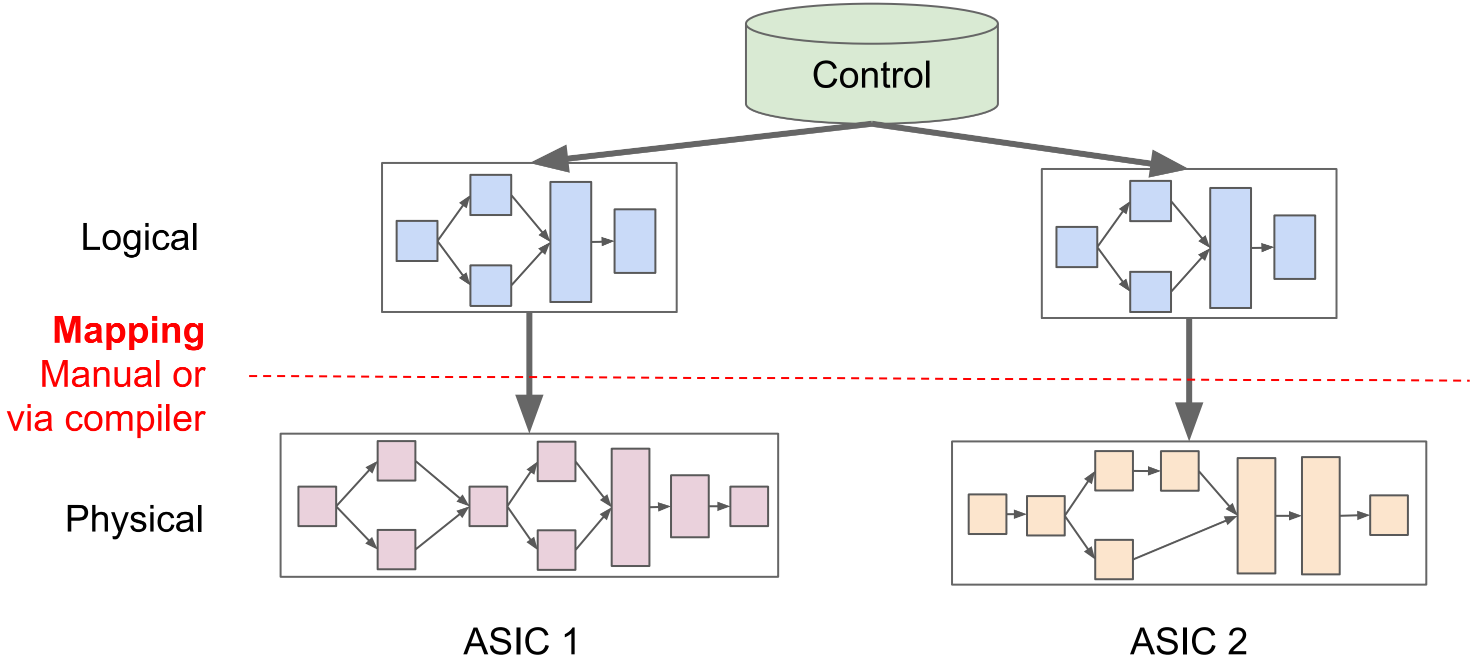
```
device_id: 1
election_id { … }
updates {
  type: INSERT
  entity {
    table_entry {
      table_id: 33581985
      match {
        field_id: 1
        lpm {
          value: "\n\000\001\001"
          prefix_len: 32
        }
      }
      action {
        action_id: 16786453
        params {
          param_id: 1
          value: "\000\000\000\000\000\n"
        }
        params {
          param_id: 2
          value: "\000\007"
…
```

An aside on Stratum and fixed-function switches...

Role of P4 for fixed-function chips

Slide courtesy: Google

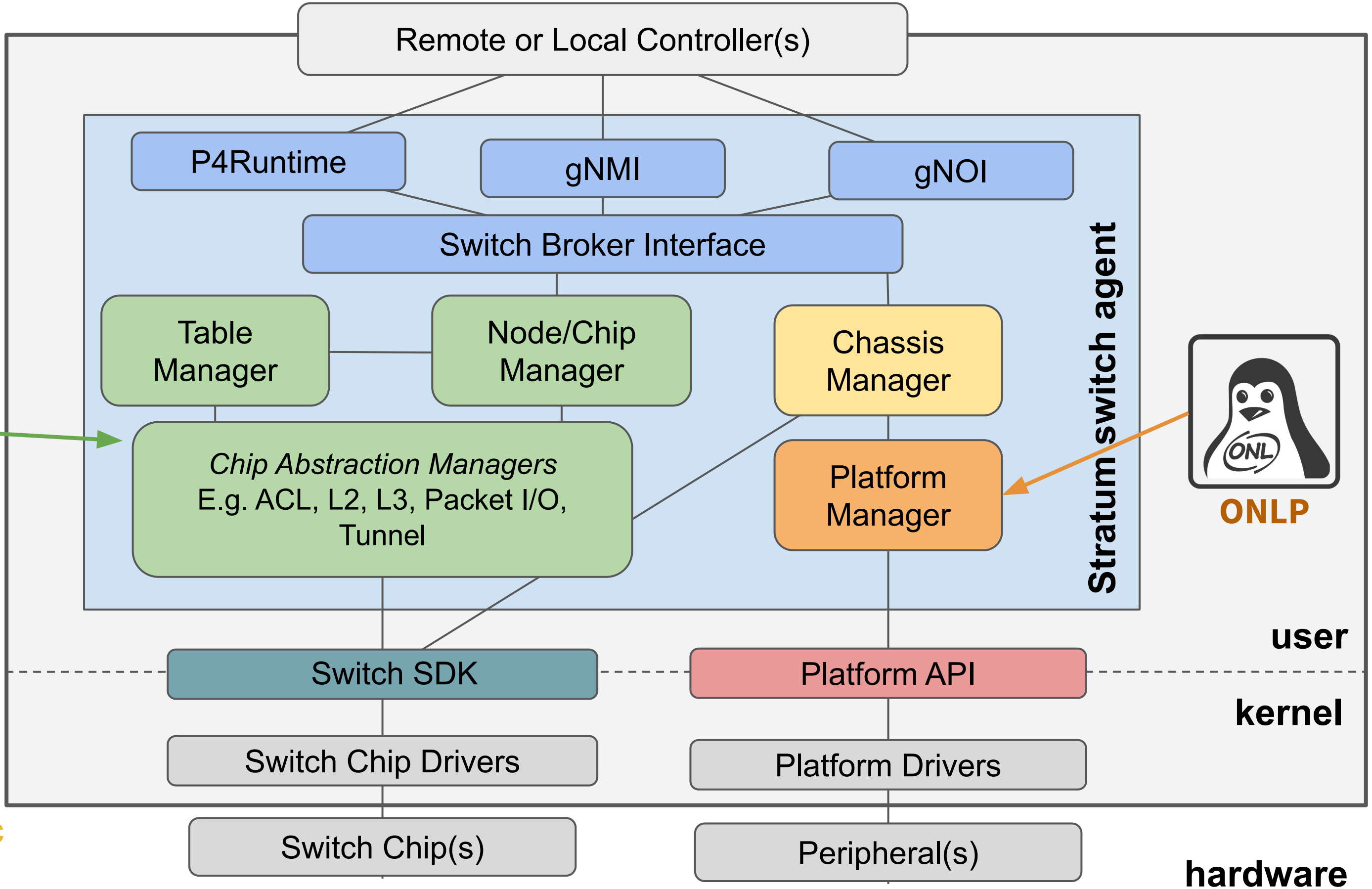
- P4 program tailored to apps / role - does not describe the hardware
- Switch maps program to fixed-function ASIC
- Enables portability



Project Stratum (ONF)

- **Vendor-agnostic implementation of next-gen SDN interfaces**
  - P4Runtime, gNMI (config), and gNOI (operations)
  - Production-ready, minimize bugs and improves time to market for vendor implementations
- **P4 compiler backend for fixed pipeline model (FPM)**
  - Produces mapping between P4-defined tables and SDK tables/APIs
  - Initial support for Broadcom Tomahawk and SDKLT
- **Extensive conformance test framework**
  - Along with a repository of tests
  - Make sure that vendor-specific pieces are implemented as expected

Stratum High-level Architectural Components



Current support for

- **Barefoot Tofino**
- **BRCM Tomahawk**
- **BMv2 sw switch**

Common (HW agnostic)
Chip specific
Platform specific
Chip and Platform specific

ONOS support for P4Runtime

Design goals

ONOS originally designed to work with OpenFlow and fixed-function switches

Extended it to:

1. **Allow ONOS users to bring their own P4 program**
2. **Allow *existing* apps to control *any* P4 pipeline without changing the app**
    - i.e. provide app portability across many P4 pipelines
    - Re-use Trellis apps with other P4-capable switches
3. **Allow *new* apps to control custom P4-defined protocols**
    - e.g. apps for BNG and 4G/5G S/PGW control plane

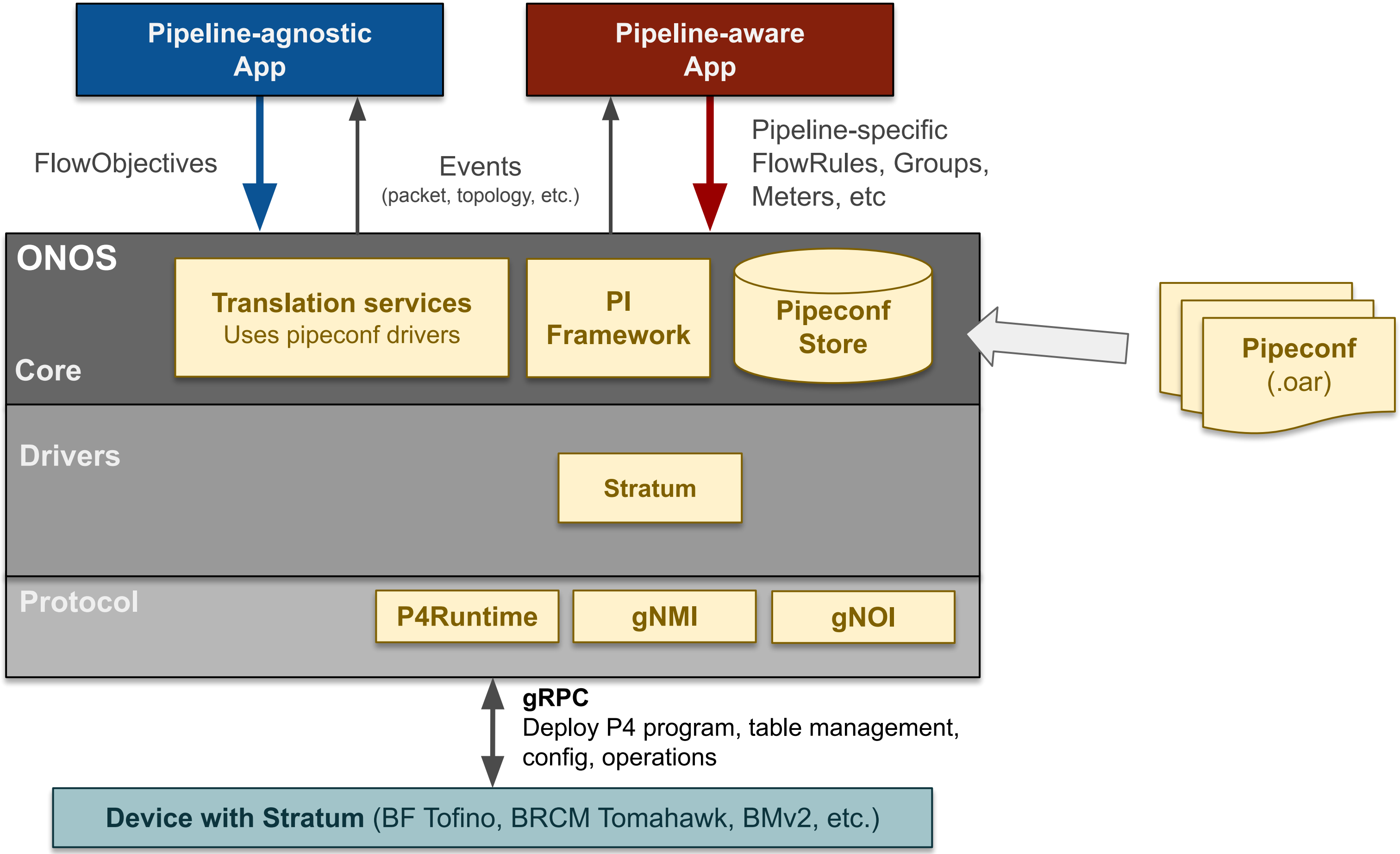
Pipeconf - Bring your own pipeline!

- **Package together everything necessary to let ONOS understand, control, and deploy an arbitrary pipeline**
- **Provided to ONOS as an app**
  - Can use `.oar` binary format for distribution

pipeconf.oar

1. **Pipeline model**
   - Description of the pipeline understood by ONOS
   - Automatically derived from P4Info
2. **Target-specific binaries to deploy pipeline to device**
   - E.g. BMv2 JSON, Tofino binary, FPGA bitstream, etc.
3. **Pipeline-specific driver behaviors**
   - E.g. mapping of ONOS flow programming API to P4 pipeline

Pipeconf support in ONOS



PI framework (@beta)

- **PI** = (data plane) protocol-independent
- **Model**: abstraction derived from P4Info
- **Runtime**: abstraction derived from P4Runtime
- **Service**: to operate on PI-capable devices

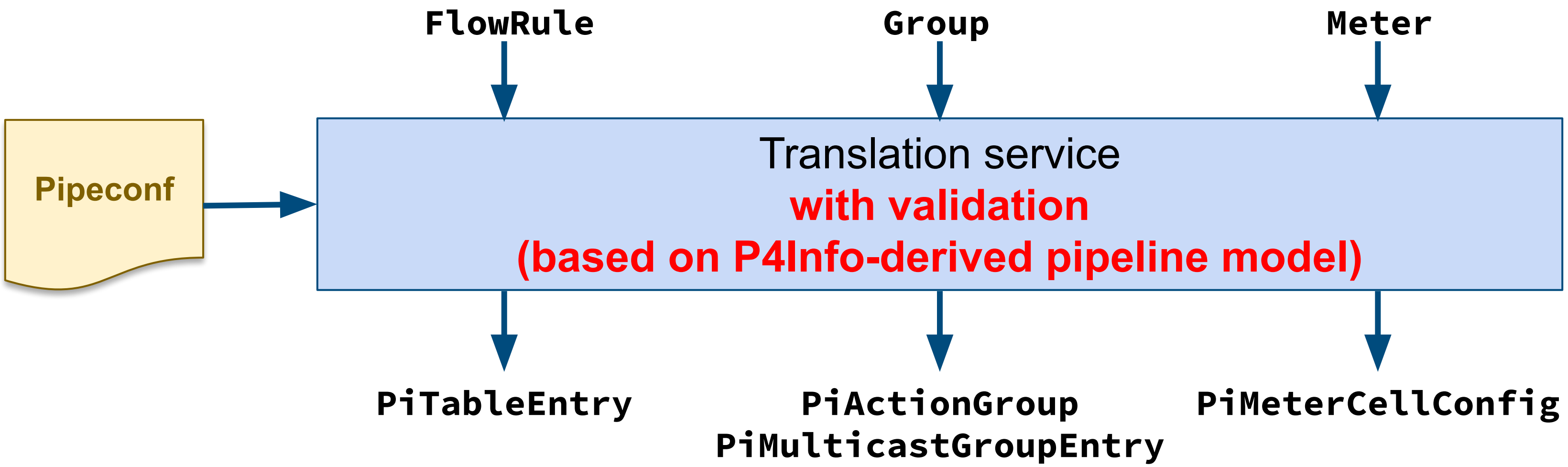
```
onos/core/api/.../pi/model
DefaultPiPipeconf.java
PiActionId.java
PiActionModel.java
PiActionParamId.java
PiActionParamModel.java
PiActionProfileId.java
PiActionProfileModel.java
PiControlMetadataId.java
PiControlMetadataModel.java
PiCounterId.java
PiCounterModel.java
PiCounterType.java
PiData.java
PiMatchFieldId.java
PiMatchFieldModel.java
PiMatchType.java
PiMeterId.java
PiMeterModel.java
PiMeterType.java
...
```

```
onos/core/api/.../pi/runtime
PiAction.java
PiActionGroup.java
PiActionGroupHandle.java
PiActionGroupId.java
PiActionGroupMember.java
PiActionGroupMemberHandle.java
PiActionGroupMemberId.java
PiActionParam.java
PiControlMetadata.java
PiCounterCell.java
PiCounterCellData.java
PiCounterCellId.java
PiEntity.java
PiEntityType.java
PiExactFieldMatch.java
PiFieldMatch.java
PiGroupKey.java
PiHandle.java
PiLpmFieldMatch.java
...
```

```
onos/core/api/.../pi/service
PiFlowRuleTranslationStore.java
PiFlowRuleTranslator.java
PiGroupTranslationStore.java
PiGroupTranslator.java
PiMeterTranslationStore.java
PiMeterTranslator.java
PiMulticastGroupTranslationStore.java
PiMulticastGroupTranslator.java
PiPipeconfConfig.java
PiPipeconfDeviceMappingEvent.java
PiPipeconfMappingStore.java
PiPipeconfMappingStoreDelegate.java
PiPipeconfService.java
PiPipeconfWatchdogEvent.java
PiPipeconfWatchdogListener.java
PiPipeconfWatchdogService.java
PiTranslatable.java
PiTranslatedEntity.java
PiTranslationEvent.java
...
```

Translation Service

- Core service
- Translate pipeline-specific entities from protocol-dependent representations to PI ones
  - E.g. OpenFlow-like headers/criteria and actions to P4-specific ones



Flow operations

Pipeconf-based 3-phase translation:

1. Flow Objective → Flow Rule

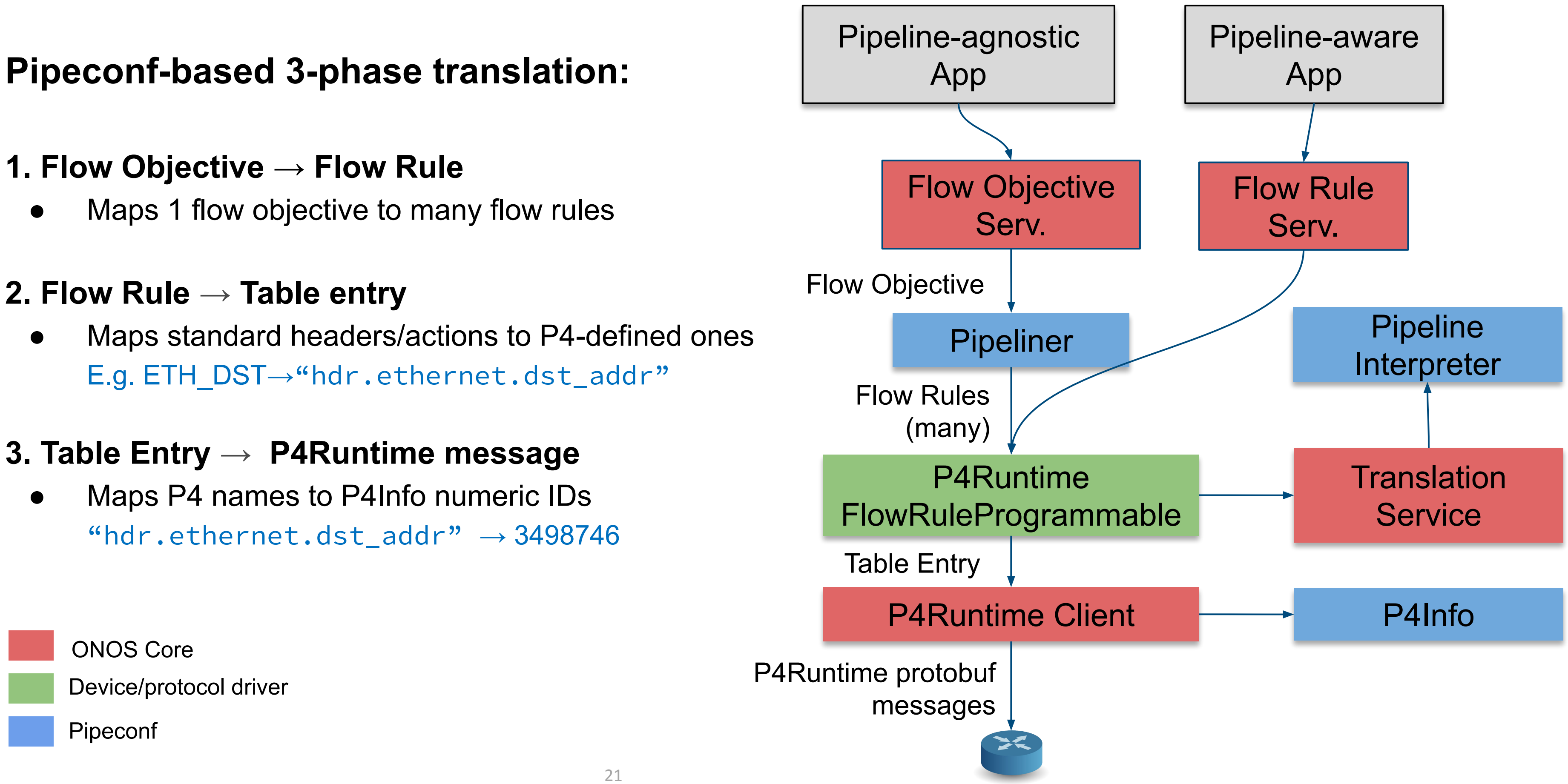
- Maps 1 flow objective to many flow rules

2. Flow Rule → Table entry

- Maps standard headers/actions to P4-defined ones
  E.g. ETH_DST→`“hdr.ethernet.dst_addr”`

3. Table Entry → P4Runtime message

- Maps P4 names to P4Info numeric IDs
  `“hdr.ethernet.dst_addr”` → 3498746



PipelineInterpreter (driver behavior)

- Provide mapping from OpenFlow-derived ONOS headers/actions to P4 program-specific entities
- Example: flow rule translation
  - Match
    - 1:1 mapping between ONOS known headers and P4 header names
    - E.g. `ETH_DST` → `ethernet.dst_addr` (name defined in P4 program)
  - Action
    - ONOS defines standard actions as in OpenFlow (output, set field, etc.)
    - P4 allows only one action per table entry, ONOS many (as in OpenFlow)
    - E.g. header rewrite + output: 2 actions in ONOS, 1 action with 2 parameters in P4
    - How to map many actions to one? Need interpretation logic (i.e. Java code)!

P4Runtime support in ONOS 2.1

P4Runtime control entity	ONOS API
Table entry	Flow Rule Service, Flow Objective Service Intent Service
Packet-in/out	Packet Service
Action profile group/members, PRE multicast groups, clone sessions	Group Service
Meter	Meter Service (indirect meters only)
Counters	Flow Rule Service (direct counters) P4Runtime Client (indirect counters)
Pipeline Config	Pipeconf

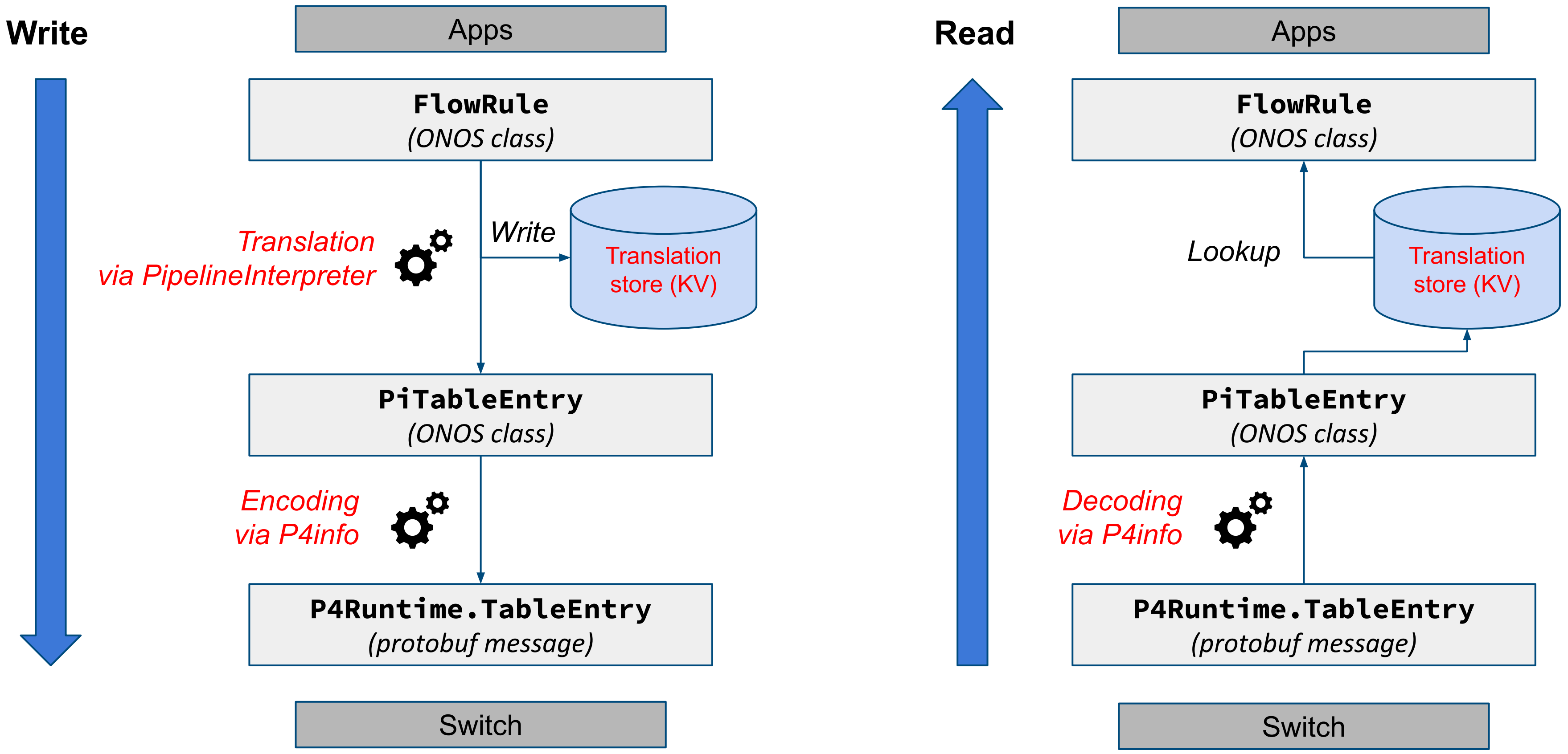
Unsupported features - community help needed!
Parser value sets, registers, digests

ONOS+P4 workflow recap

- **Write P4 program and compile it**
  - Obtain P4Info and target-specific binaries to deploy on device
- **Create pipeconf**
  - Implement pipeline-specific driver behaviours (Java):
    - Pipeliner (optional - if you need FlowObjective mapping)
    - Pipeline Interpreter (to map ONOS known headers/actions to P4 program ones)
    - Other driver behaviors that depend on pipeline
- **Use existing pipeline-agnostic apps**
  - Apps that program the network using FlowObjectives
- **Write new pipeline-aware apps**
  - Apps can use same string names of tables, headers, and actions as in the P4 program

Performance considerations

Performance overhead



Relevant use cases and metrics

- **ONOS in production at major US carrier**
  - Leaf-spine fabric for subscriber access
  - Proactive flow programming, routing-heavy (100s of 1000s of routes)
- **Known pain points**
  - Initial switch provisioning / reboot / failure re-routing
    - Insert/update routes
  - Flow rule reconciliation (periodic, every 10-100 seconds)
    - Read device state and compare with ONOS store
- **Relevant metrics**
  - Read/write operations throughput
  - Latency for batched write operations
  - Memory utilization

Proposed testing methodology

- **Measure relevant metrics with up to 1M routes**
- **Remove overhead of switch implementation (e.g. slow ASIC writes)**
  - Use Stratum “Dummy” switch (yet to be open sourced)
    - Write/read from memory instead of ASIC
  - Or, implement dummy P4Runtime server
    - E.g. in golang or C, easy with gRPC auto-generated stubs
- **Remove/minimize RTT between switch and ONOS**
  - Ideally run ONOS and P4Runtime process on the same machine

Conclusions

- ONOS extended to add support for P4 & P4Runtime
- Maintain backward compatibility with existing northbound APIs via internal translation
    - FlowRule, FlowObjective API $\longrightarrow$ P4Runtime protobuf messages
- Translation adds overhead
- Proposed activity: measure ONOS performance when using P4Runtime in relevant use causes (routing heavy)

Get started: ONOS+P4 tutorial

- **Basic**
  - Learn the basics of P4Runtime and ONOS with hands-on exercises
  - https://wiki.onosproject.org/x/MwP2

- **Advanced**
  - Build a leaf-spine fabric based on SRv6 with P4 and ONOS
  - https://wiki.onosproject.org/x/xIFfAg

Thanks!