Programmable Networks – P4 overview

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Worlds Fastest Most Programmable Networks Barefoot Networks white paper, 2016.

Why programmable networks

• Deploy tests and probes, can reduce time to recover from an outage
• Monitoring networks can be eliminated because network can now monitor itself
• Eliminate redundant equipment. For example, big data-centers today commonly deploy expensive middleboxes – load-balancers, address translators, complex Network Function Virtualization (NFV) cluster of thousands of servers to load-balance incoming packets across web servers.
• Only slow networks are programmable now. NPUs and FPGAs exist and are flexible. But are 1/100th performance of fixed-function ASICs
Barefoot Networks

• Created first programmable chip that performs like ASIC
• P4 - Programming Protocol-independent Packet Processors – www.p4.org exists now as an independent entity to develop a rich open source ecosystem
• P4 offers a programming abstraction that is familiar to network owners rather than VHDL
• Proposed architecture does for networking what DSP did for signal processing, GPU did for graphics and TPU is doing for machine learning
• Programs are written in a high level domain specific language (P4), compiled down by Barefoot Capilano compiler, and optimized to run at full line-rate on PISA device
P4

P4 is a high-level language for programming protocol-independent packet processors. OpenFlow explicitly specifies protocol headers on which it operates. This set has grown from 12 to 41 fields in a few years, increasing complexity of specification.

(1) Reconfigurability: Programmers should be able to change the way switches process packets once deployed.
(2) Protocol independence: Switches should not be tied to any specific network protocols.
(3) Target independence: independent of specifics of underlying hardware.

Future switches should support mechanisms for parsing packets and matching header allowing controller applications to leverage capabilities of common, open interface (i.e., a new OpenFlow 2.0 API).
What does it do

FIGURE 1: Opportunity to “compile” the networks
Steps in P4

Switch Configuration

Parse Graph  |  Control Program  |  Table Config  |  Action Set

Forwarding rules

INPUT  |  PARSER  |  BUFFER

Ingress Pipeline
Packet Mods + Egress Selection

Output

ACTION

Match Action  |  Match Action

Egress Pipeline
Packet Mods

†Barefoot Networks * Intel ‡Stanford University **Princeton University ¶Google §Microsoft Research.
Header Formats

header ethernet {
  fields {
    dst_addr : 48;
    //width in bits
    src_addr : 48;
    ethertype : 16;
  }
}

header vlan {
  fields {
    pcp : 3;
    cfi : 1;
    vid : 12;
    ethertype : 16;
  }
}
Packet Parser

Parsing starts in start state and proceeds until an explicit stop state is reached.

Extracted headers are forwarded to match-action processing.

```
parser start {
  ethernet;
}
parser ethernet {
  switch(ethertype) {
    case 0x8100: vlan;
    case 0x9100: vlan;
    case 0x800: ipv4;
  // Or cases
  }
}
parser vlan {
  switch(ethertype) {
    case 0xaaaa: mTag;
    case 0x800: ipv4;
  // Or cases
  }
}
parser mTag {
  switch(ethertype) {
    case 0x800: ipv4;
  // Or cases
  }
}
```
Table specification

• Programmer describes how header fields are to be matched in match+action stages (e.g., should they be exact matches, ranges, or wildcards?) and what actions should be performed when a match occurs

• Reads attribute declares which fields to match, qualified by match type (exact, ternary, etc)

• Actions attribute lists possible actions which may be applied to a packet by table
Table action

P4’s primitive actions include:

- **set field**: Set a header to a value.
  Masked sets are supported.
- **copy field**: Copy one field to another.
- **add header**: Set a specific header instance (and all its fields) as valid.
- **remove header**: Delete ('pop”) a header (and all its fields) from a packet.
- **increment**: Increment or decrement value in a field.
- **checksum**: Calculate a checksum over some set of header fields (e.g., an IPv4 checksum).

```plaintext
action add_mTag(up1, up2, down1, down2, egr_spec) {
    add_header(mTag);
    // Copy VLAN ethertype to mTag
    copy_field(mTag.ethertype, vlan.ethertype);
    // Set VLAN's ethertype to signal mTag
    set_field(vlan.ethertype, 0xaaaa);
    set_field(mTag.up1, up1);
    set_field(mTag.up2, up2);
    set_field(mTag.down1, down1);
    set_field(mTag.down2, down2);
    // Set destination egress port as well
    set_field(metadata.egress_spec, egr_spec);
}
```

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Control Program

Once tables and actions are defined, only remaining task is to specify flow of control from one table to next

Control flow is specified as a program via a collection of functions, conditionals, and table references

close main() {
    // Verify mTag state and port are consistent
    table(source_check);
    // If no error from source_check, continue
    if (!defined(metadata.ingress_error))
    {
        // Attempt to switch to end hosts
        table(local_switching);
        if (!defined(metadata.egress_spec))
        {
            // Not a known local host; try mtagging
Conclusion

• Proposed a step towards more flexible switches whose functionality is specified and may be changed once deployed

• Programmer decides how forwarding plane processes packets without worrying about implementation details

• A compiler transforms an imperative program into a table dependency graph that can be mapped to many target switches, including optimized hardware implementations