Definido por software
Rede

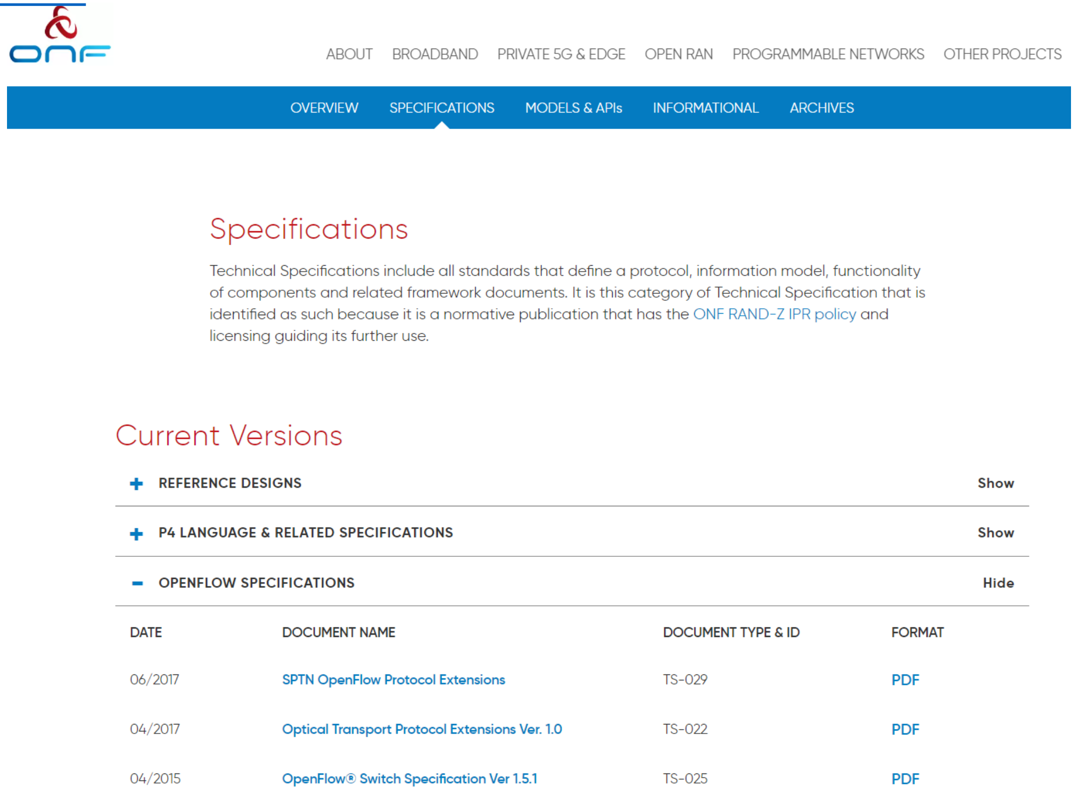
SDN

Rede definida por software

- Objetivo
  - Uma ferramenta para permitir um maior grau de controle sobre dispositivos de rede e fluxo de tráfego
- Aspectos principais
  - O plano de controle é separado do dispositivo que implementa o plano de dados
  - Um único plano de controle é usado para gerenciar vários dispositivos de rede
- Implantações iniciais
  - Universidades: experimentar novos protocolos radicais em paralelo com o tráfego existente
  - Data centers ocupados: supere o limite de tags de ID de VLAN (4095)
- Protocolos:
  - OpenFlow (primeiro)
  - P4 (agora)

OpenFlow

- Padronizado pela ONF – Open Networking Foundation
- https://opennetworking.org/software-definedstandards/specifications/
- Atualmente na versão 1.5



ABOUT BROADBAND PRIVATE 5G & EDGE OPEN RAN PROGRAMMABLE NETWORKS OTHER PROJECTS

OVERVIEW SPECIFICATIONS MODELS & APIs INFORMATIONAL ARCHIVES

Specifications

Technical Specifications include all standards that define a protocol, information model, functionality of components and related framework documents. It is this category of Technical Specification that is identified as such because it is a normative publication that has the ONF RAND-Z IPR policy and licensing guiding its further use.

Current Versions

+ REFERENCE DESIGNS Show

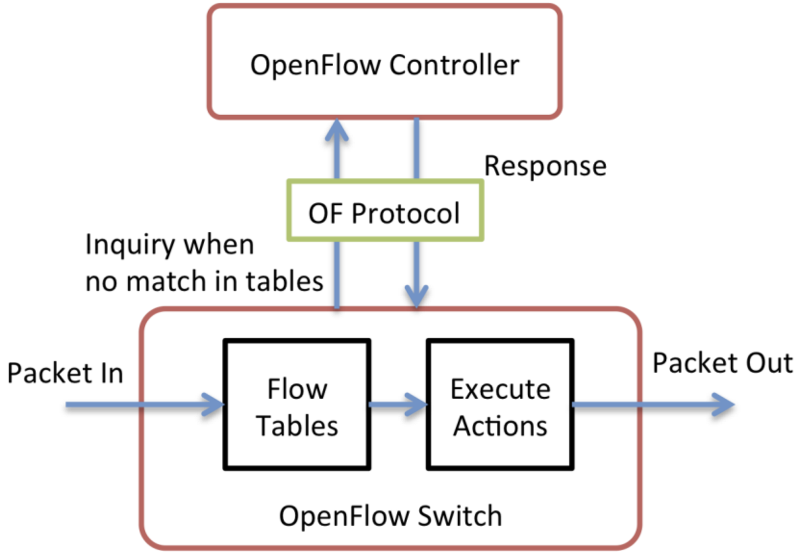
+ P4 LANGUAGE & RELATED SPECIFICATIONS Show

– OPENFLOW SPECIFICATIONS Hide

DATE	DOCUMENT NAME	DOCUMENT TYPE & ID	FORMAT
06/2017	SPTN OpenFlow Protocol Extensions	TS-029	PDF
04/2017	Optical Transport Protocol Extensions Ver. 1.0	TS-022	PDF
04/2015	OpenFlow® Switch Specification Ver 1.5.1	TS-025	PDF

OpenFlow

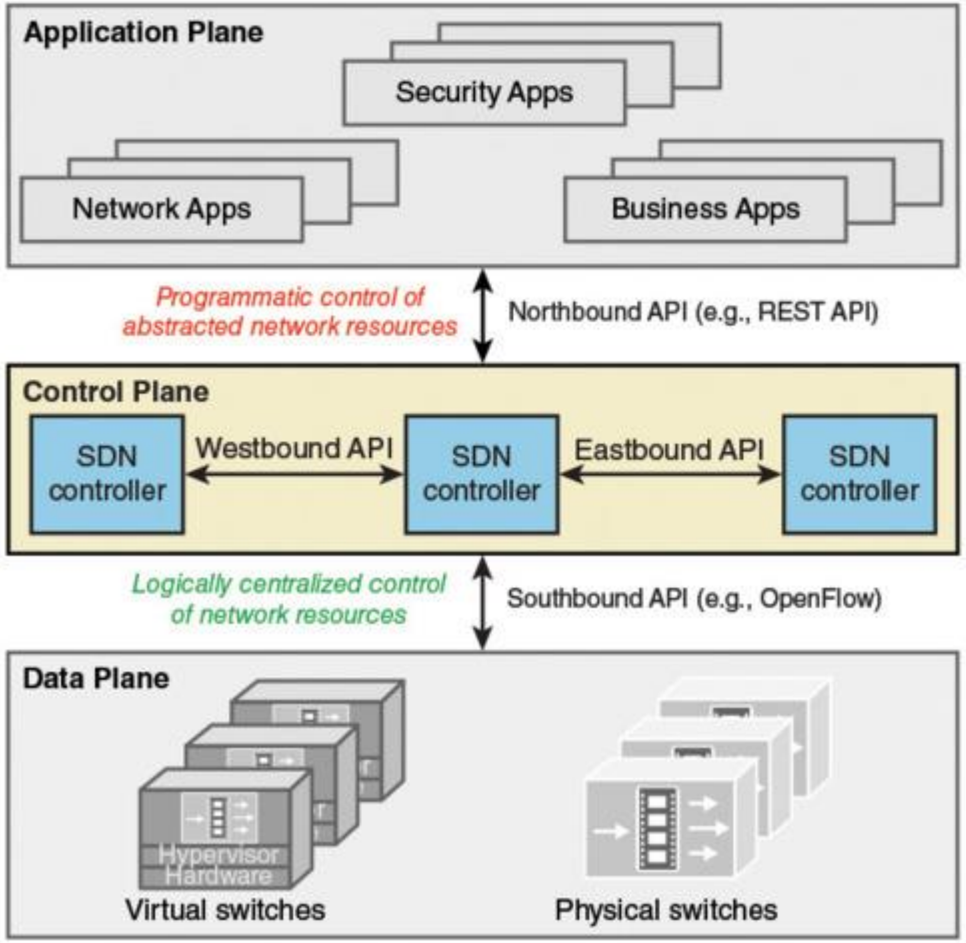
- Um protocolo existente entre switches SDN e uma nova entidade
  - Controlador SDN
- Permite que o controlador SDN gerencie tabelas de fluxo em switches SDN
- O switch SDN contém
  - Agente Openflow
  - Tabelas de fluxo
  - Executa pesquisa e encaminhamento de pacotes
  - É capaz de se comunicar (com segurança) com o controlador
- Uma tabela de fluxo é composta por
  - Entradas de fluxo (corresponde às propriedades nos cabeçalhos dos pacotes)
  - Contadores (para atividade)
  - Um conjunto de ações a serem aplicadas (aos pacotes correspondentes)
  - Quando nenhuma ação estiver presente, o switch pode
    - Solte o pacote
    - Pergunte ao controlador o que fazer



Fonte: fibra óptica-transceptor-module.com

Controlador OpenFlow

- Controlador
  - Serviço existente em um servidor, que utiliza o protocolo OpenFlow para interagir com switches SDN
  - Formula fluxos e mudanças de programas
  - É capaz de receber diretivas de aplicativos externos por meio da API REST Northbound



Controlador OpenFlow

- Muitos sabores existentes
  - ONOS – Sistema Operacional de Rede Aberta
    - https://opennetworking.org/onos/
  - TeraFlow SDN
    - https://tfs.etsi.org
  - OpenDaylight
    - https://opendaylight.org
  - Floodlight (última versão de 2016)
    - https://floodlight.atlassian.net
  - NOX (10 sem manutenção)
  - POX (versão Python do NOX com alguma manutenção) https://noxrepo.github.io/pox-doc/html/
  - Ryu (sem manutenção desde 2017)
    - https://ryu-sdn.org/
  - Trema (5 anos desde a última atualização)
    - https://github.com/trema/trema
  - Frenético (último lançamento: 2019)
    - https://github.com/frenetic-lang/frenetic

Diferenças entre controladores SDN

- Pesquisa versus produção
- Linguagem de programação
- Desempenho
- Curva de aprendizado
- Base de usuários e suporte
- Foco
  - Suporte à API Southbound
  - API para o norte
  - Versão OpenFlow

A Qualitative and Quantitative assessment of SDN Controllers

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Abstract—**With the increasing number of connected devices, new challenges are being raised in the networking field. Software Defined Networking (SDN) enables a greater degree of dynamism and simplification for the deployment of future 5G networks. In such networks, the controller plays a major role by being able to manage forwarding entities, such as switches, through the application of flow-based rules via a southbound (SB) interface. In turn, the controller itself can be managed by means of actions and policies provided by high-level network functions, via a northbound (NB) interface.**

The growth of SDN integration in new mechanisms and network architectures led to the development of different controller solutions, with a wide variety of characteristics. Despite existing studies, the most recent evaluations of SDN controllers are focused only on performance and are not up to date, since new versions of the most popular controllers are constantly being released. As such, this work provides a wider study of several open-source controllers, (namely, OpenDaylight (ODL), Open Network Operative System (ONOS), Ryu and POX), by evaluating not only their performance, but also their characteristics in a qualitative way. Taking performance as a critical issue among SDN controllers, we quantitatively evaluated several criteria by benchmarking the controllers under different operational conditions, using the Cbench tool.

Keywords—Software-Defined Networking, OpenFlow, SDN controller.

reachability optimization towards the users, and the users themselves want overall better service. Simultaneously satisfying involved actors is a highly complex task, whose harmonization is only achieved through careful planning and overprovisioning of networking resources. Nonetheless, the increase in generated data [1] and the need to dynamically adapt to changing situations in a cost-effective way, are demanding for more flexible and adaptive network control mechanisms. As a result, SDN has emerged.

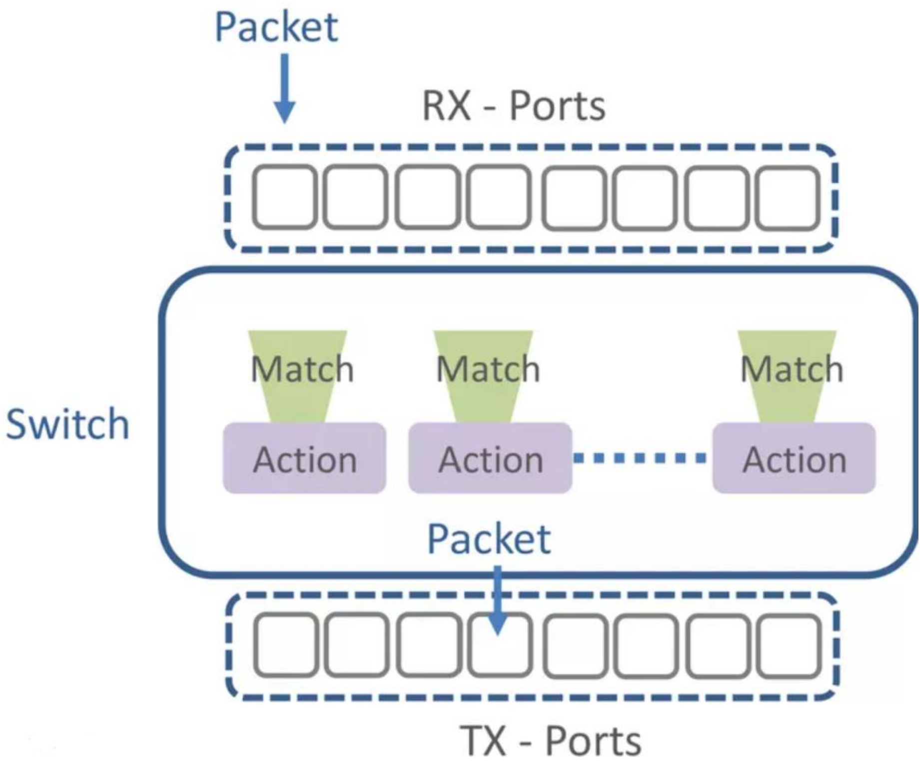
SDN provides the separation of the network control plane from the forwarding plane, allowing more control, adaptability, agility and overall cost reduction. By having a complete view of the network, an SDN controller plays an extremely important role in such networks as it can manage the network structure and services dynamically.

Several SDN controllers exist, with most of them under continuous development. This diversity, which originated from the different needs of operators and research teams that resulted in the development of their own controller versions, made comparison efforts more difficult.

This diversity is evidenced as each controller presents different Northbound (NB) and Southbound (SB) interfaces (which allow it to be interfaced by high-level entities and to control forwarding entities, respectively), development

Chave SDN

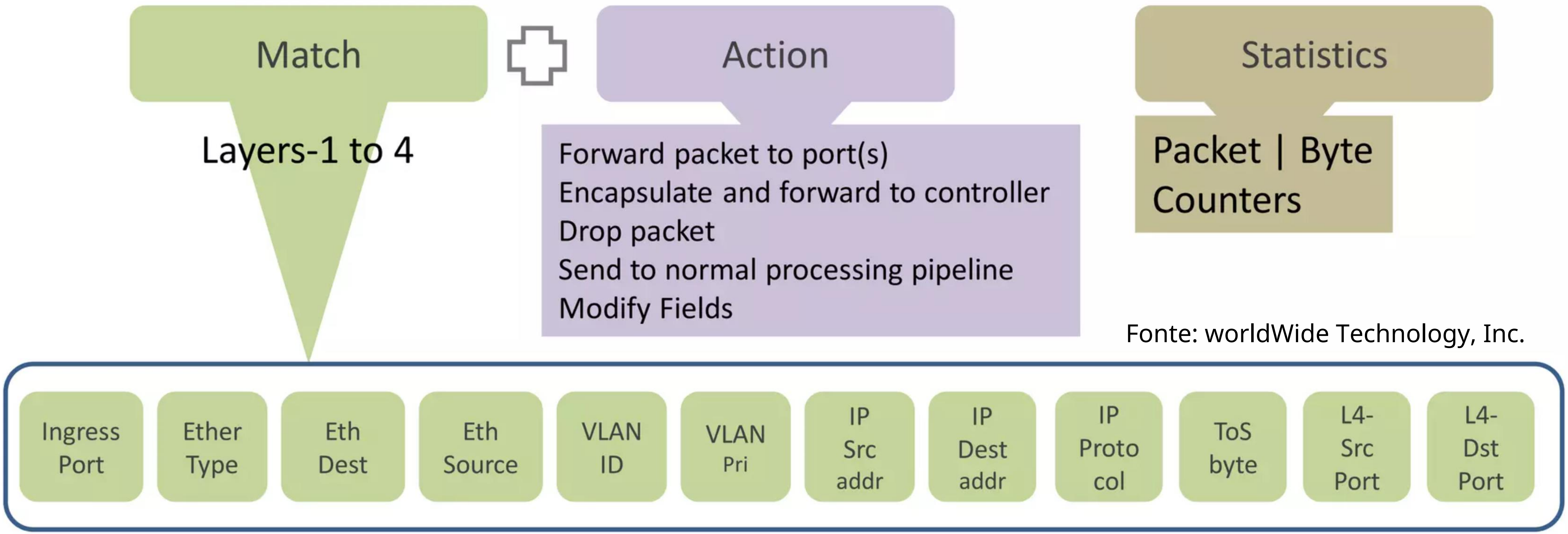
- Possui um agente OpenFlow capaz de se comunicar com o controlador
- Processa comandos recebidos pelo controlador
- Plano de dados de um switch
  - Portas
  - Tabelas de fluxo
  - Fluxos
  - Classificadores (correspondência)
  - Modificadores e ações
- Os pacotes são combinados com fluxos em tabelas de fluxo usando os match/classifiers
- Os fluxos contêm conjuntos de modificadores e ações que são aplicadas a cada pacote ao qual ele corresponde.



Fonte: worldWide Technology, Inc.

Switch SDN – Tabela de fluxo

- Cada entrada da tabela de fluxo contém: Correspondência, Ação e contadores



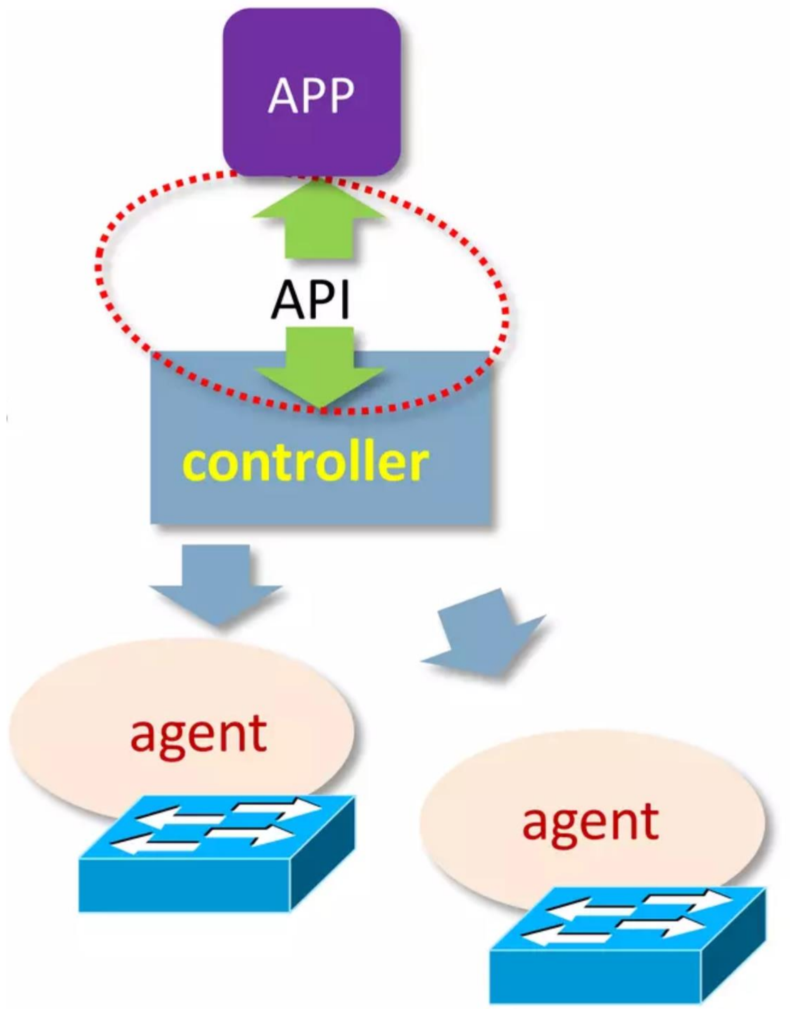
Fonte: worldWide Technology, Inc.

Chave SDN - Ações

- Quando um switch se conecta pela primeira vez a um controlador, ele especifica quais ações são suportadas
  - Nem todos os switches precisam implementar todas as ações do OpenFlow
- Exemplos de ações
  - Encaminhar um pacote para um conjunto de portas
  - Solte um pacote
  - Adicionar, modificar ou remover ID de VLAN ou prioridade por porta de destino
  - Modifique o IP DSCP (ou seja, QoS)
  - Modifique o endereço MAC de destino
  - Envie o pacote para o controlador OpenFlow (Packet In)
  - Receba o pacote do controlador OpenFlow e envie-o para as portas (Packet out)

Como “direcionar” o controlador?

- A interface Northbound permite protocolos Northbound
- Permite que aplicativos e sistemas de orquestração programem a rede e solicitem serviços
- Fornece uma interface de abstração de rede para aplicativos
- A abstração é importante ao gerenciar redes diferentes elementos



Exemplos de protocolo Northbound

- Não há nada padronizado, mas existem “tipos” de protocolos utilizados
- API REST (baseada na web) – aplicativos que são executados em diferentes máquinas ou espaços de endereço no controlador
- Navegador da Web
  - http://<IP do controlador SDN>:8080/....
- WebSockets
- A estrutura OSGi é usada para aplicativos que serão executados no mesmo espaço de endereço que o controlador.
  - Iniciativa de Gateway de Serviço Aberto

Rumo à próxima geração de SDN

OpenFlow: Enabling Innovation in Campus Networks

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Authors take full responsibility for this article's technical content.
Comments can be posted through CCR Online.

ABSTRACT

This whitepaper proposes OpenFlow: a way for researchers to run experimental protocols in the networks they use every day. OpenFlow is based on an Ethernet switch, with an internal flow-table, and a standardized interface to add and remove flow entries. Our goal is to encourage networking vendors to add OpenFlow to their switch products for deployment in college campus backbones and wiring closets. We believe that OpenFlow is a pragmatic compromise: on one hand, it allows researchers to run experiments on heterogeneous switches in a uniform way at line-rate and with high port-density; while on the other hand, vendors do not need to expose the internal workings of their switches. In addition to allowing researchers to evaluate their ideas in real-world traffic settings, OpenFlow could serve as a useful campus component in proposed large-scale testbeds like GENI. Two buildings at Stanford University will soon run OpenFlow networks, using commercial Ethernet switches and routers. We will work to encourage deployment at other schools; and We encourage you to consider deploying OpenFlow in your university network too.

Categories and Subject Descriptors

C.2 [**Internetworking**]: Routers

General Terms

Experimentation, Design

Keywords

Ethernet switch, virtualization, flow-based

1. THE NEED FOR PROGRAMMABLE NETWORKS

Networks have become part of the critical infrastructure of our businesses, homes and schools. This success has been both a blessing and a curse for networking researchers; their work is more relevant, but their chance of making an impact is more remote. The reduction in real-world impact of any given network innovation is because the enormous installed base of equipment and protocols, and the reluctance to experiment with production traffic, which have created an exceedingly high barrier to entry for new ideas. Today, there is almost no practical way to experiment with new network protocols (e.g., new routing protocols, or alternatives to IP) in sufficiently realistic settings (e.g., at scale carrying real traffic) to gain the confidence needed for their widespread deployment. The result is that most new ideas from the networking research community go untried and untested; hence the commonly held belief that the network infrastructure has "ossified".

Having recognized the problem, the networking community is hard at work developing programmable networks, such as GENI [1] a proposed nationwide research facility for experimenting with new network architectures and distributed systems. These programmable networks call for programmable switches and routers that (using *virtualization*) can process packets for multiple isolated experimental networks simultaneously. For example, in GENI it is envisaged that a researcher will be allocated a *slice* of resources across the whole network, consisting of a portion of network links, packet processing elements (e.g. routers) and end-hosts; researchers program their slices to behave as they wish. A slice could extend across the backbone, into access networks, into college campuses, industrial research labs, and include wiring closets, wireless networks, and sensor networks.

Virtualized programmable networks could lower the barrier to entry for new ideas, increasing the rate of innovation in the network infrastructure. But the plans for nationwide facilities are ambitious (and costly), and it will take years for them to be deployed.

This whitepaper focuses on a shorter-term question closer to home: *As researchers, how can we run experiments in our campus networks?* If we can figure out how, we can start soon and extend the technique to other campuses to benefit the whole community.

To meet this challenge, several questions need answering, including: In the early days, how will college network administrators get comfortable putting experimental equipment (switches, routers, access points, etc.) into their network? How will researchers control a portion of their local network in a way that does not disrupt others who depend on it? And exactly what functionality is needed in network

2008

P4: Programming Protocol-Independent Packet Processors

Pat Bosshart[†], Dan Daly[*], Glen Gibb[†], Martin Izzard[†], Nick McKeown[‡], Jennifer Rexford[**], Cole Schlesinger[**], Dan Talayco[†], Amin Vahdat[¶], George Varghese[§], David Walker[**]
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ABSTRACT

P4 is a high-level language for programming protocol-independent packet processors. P4 works in conjunction with SDN control protocols like OpenFlow. In its current form, OpenFlow explicitly specifies protocol headers on which it operates. This set has grown from 12 to 41 fields in a few years, increasing the complexity of the specification while still not providing the flexibility to add new headers. In this paper we propose P4 as a strawman proposal for how OpenFlow should evolve in the future. We have three goals: (1) Reconfigurability in the field: Programmers should be able to change the way switches process packets once they are deployed. (2) Protocol independence: Switches should not be tied to any specific network protocols. (3) Target independence: Programmers should be able to describe packet-processing functionality independently of the specifics of the underlying hardware. As an example, we describe how to use P4 to configure a switch to add a new hierarchical label.

1. INTRODUCTION

Software-Defined Networking (SDN) gives operators programmatic control over their networks. In SDN, the control plane is physically separate from the forwarding plane, and one control plane controls multiple forwarding devices. While forwarding devices could be programmed in many ways, having a common, open, vendor-agnostic interface (like OpenFlow) enables a control plane to control forwarding devices from different hardware and software vendors.

Version	Date	Header Fields
OF 1.0	Dec 2009	12 fields (Ethernet, TCP/IPv4)
OF 1.1	Feb 2011	15 fields (MPLS, inter-table metadata)
OF 1.2	Dec 2011	36 fields (ARP, ICMP, IPv6, etc.)
OF 1.3	Jun 2012	40 fields
OF 1.4	Oct 2013	41 fields

Table 1: Fields recognized by the OpenFlow standard

The OpenFlow interface started simple, with the abstraction of a single table of rules that could match packets on a dozen header fields (e.g., MAC addresses, IP addresses, protocol, TCP/UDP port numbers, etc.). Over the past five years, the specification has grown increasingly more complicated (see Table 1), with many more header fields and multiple stages of rule tables, to allow switches to expose more of their capabilities to the controller.

The proliferation of new header fields shows no signs of stopping. For example, data-center network operators increasingly want to apply new forms of packet encapsulation (e.g., NVGRE, VXLAN, and STT), for which they resort to deploying software switches that are easier to extend with new functionality. Rather than repeatedly extending the OpenFlow specification, we argue that future switches should support flexible mechanisms for parsing packets and matching header fields, allowing controller applications to leverage these capabilities through a common, open interface (i.e., a new "OpenFlow 2.0" API). Such a general, extensible approach would be simpler, more elegant, and more future-proof than today's OpenFlow 1.x standard.

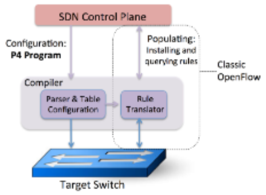


Figure 1: P4 is a language to configure switches.

Recent chip designs demonstrate that such flexibility can be achieved in custom ASICs at terabit speeds [1, 2, 3]. Programming this new generation of switch chips is far from easy. Each chip has its own low-level interface, akin to microcode programming. In this paper, we sketch the design of a higher-level language for Programming Protocol-independent Packet Processors (P4). Figure 1 shows the relationship between P4—used to configure a switch, telling it how packets are to be processed—and existing APIs (such as OpenFlow) that are designed to populate the forwarding tables in fixed function switches. P4 raises the level of abstraction for programming the network, and can serve as a

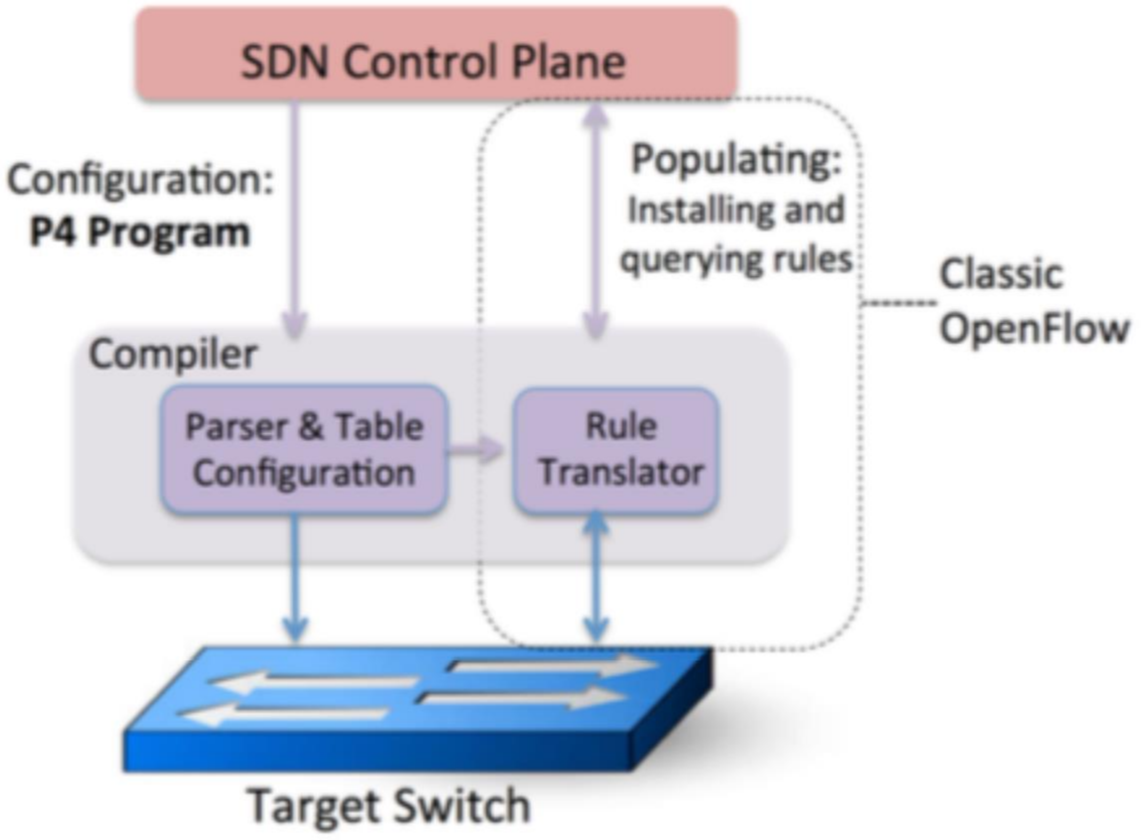
2014

Programação de processadores de pacotes independentes de protocolo (P4)

- Objetivos
  - Reconfigurável
    - O programa Data Plane pode ser alterado no campo
  - Independência de Protocolo
    - Nenhum conhecimento de organização de hardware de baixo nível é necessário
    - O compilador compila o programa para o dispositivo de destino
    - Arquitetura dependente – por exemplo, v1model.p4, p4c-xdp.p4, psa.p4
  - Independência de switch/fornecedor
  - Interface de plano de controle consistente
    - APIs do plano de controle são geradas automaticamente pelo compilador
  - Design orientado para a comunidade
    - https://p4.org

Programação de processadores de pacotes independentes de protocolo (P4)

- O programa P4 é um programa de alto nível que configura o comportamento de encaminhamento (modelo de encaminhamento abstrato)
- O compilador P4 gera o código de baixo nível para ser executado pelo destino desejado
- O OpenFlow ainda pode ser usado para instalar e consultar regras depois que o modelo de encaminhamento for definido
- Permite a definição de cabeçalhos e campos arbitrários



Cabeçalho e campos P4

- Os campos têm largura de bits e outros atributos
- Cabeçalhos são coleções de campos
  - Como uma classe instanciada em Java

```
header_type ethernet_t {
  fields {
    dstAddr     : 48;
    srcAddr     : 48;
    etherType   : 16;
  }
}

/* Instance of eth header */
header ethernet_t inner_ethernet;
```

```
header_type egress_metadata_t {
  fields {
    nhop_type   : 8;  /* 0: L2, 1: L3, 2: tunnel */
    encap_type  : 8;  /* L2 Untagged; L2ST; L2DT */
    vnid        : 24; /* gnve/vxlan vnid/gre key */
    tun_type    : 8;  /* vxlan; gre; nvgre; gnve*/
    tun_idx     : 8;  /* tunnel index */
  }
}

metadata egress_metadata_t egress_metadata;
```

Analisador

- Extrai instâncias de cabeçalho
- Seleciona um próximo “estado” retornando outra função de analisador

```
parser parse_ethernet {
  extract(ethernet);
  return select(latest.etherType) {
    ETHERTYPE_CPU  : parse_cpu_header;
    ETHERTYPE_VLAN : parse_vlan;
    ETHERTYPE_MPLS : parse_mpls;
    ETHERTYPE_IPV4 : parse_ipv4;
    ETHERTYPE_IPV6 : parse_ipv6;
    ETHERTYPE_ARP  : parse_arp_rarp;
    ETHERTYPE_RARP : parse_arp_rarp;
    ETHERTYPE_NSH  : parse_nsh;
  }
}
```

Tabela de Partida + Ação

- A representação analisada dos cabeçalhos fornece contexto para processamento dos pacotes
- Uma função de ação consiste em várias ações primitivas

```
table acl {
    reads {
        ipv4.dstAddr : ternary;
        ipv4.srcAddr : ternary;
        ipv4.protocol : ternary;
        udp.srcPort : ternary;
        udp.dstPort : ternary;
        ethernet.dstAddr : exact;
        ethernet.srcAddr : exact;
        ethernet.etherType : ternary;
    }
    actions {
        no_op;     /* permit */
        acl_drop; /* reject */
        nhop_set; /* policy-based routing */
    }
}
```

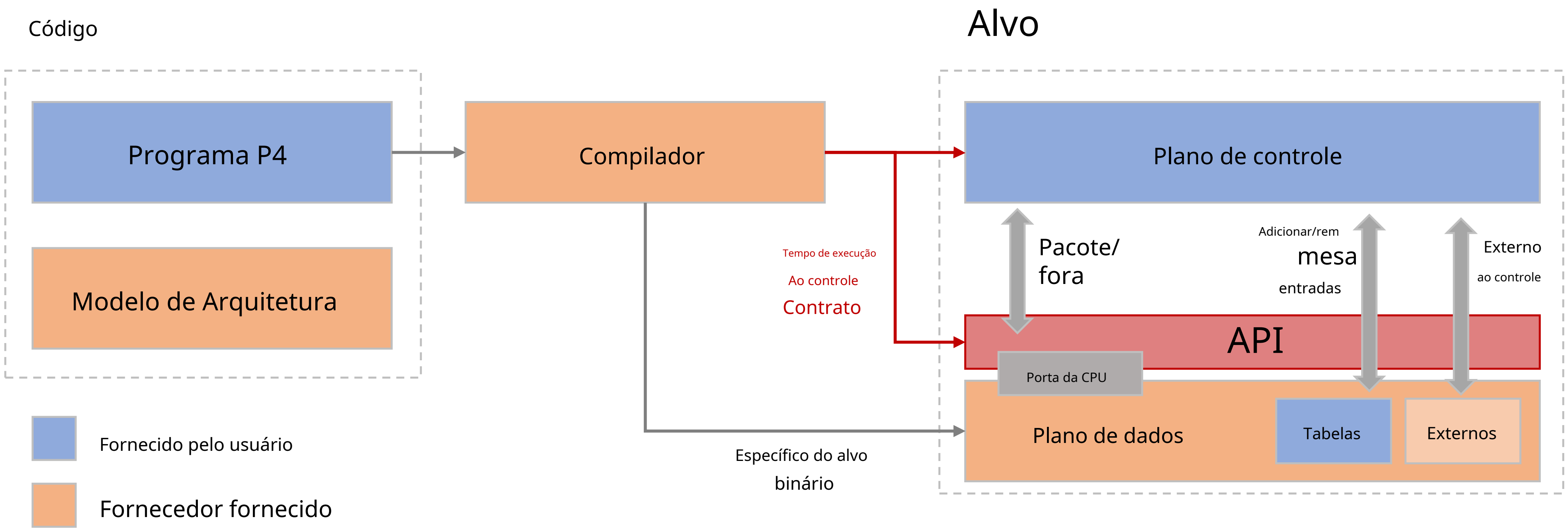
Match semantics

- **exact**
  - port_index : exact
- **ternary**
  - ethernet.srcAddr : ternary
- **valid**
  - vlan_tag[0] : valid
- **lpm**
  - ipv4.dstAddr : lpm
- **range**
  - udp.dstPort : range

Primitive actions

- modify_field, add_to_field, add, set_field_to_hash_index
- add_header, remove_header, copy_header
- push, pop
- count, meter
- generate_digest, truncate
- resubmit, recirculate
- clone_*
- no_op, drop

Programando um alvo



Tempo de execução P4

- Estrutura para controle de tempo de execução de planos de dados definidos por P4
  - API de código aberto e implementação de servidor
- P4 independente do programa
  - API não muda com o programa P4
- Permite reconfigurabilidade em campo
  - Capacidade de enviar novo programa P4 sem recompilar a pilha de software dos switches alvo
- API baseada em protobuf (serialização) e gRPC (transporte cliente/servidor)
  - Facilita a implementação de um cliente/servidor P4Runtime gerando código automaticamente para diferentes linguagens
- P4Info como contrato entre controle e plano de dados
  - Gerado pelo compilador P4
  - Necessário ao plano de controle para formatar o corpo das mensagens P4Runtime

P4 e P4Runtime são duas coisas diferentes

- P4
  - Linguagem de programação usada para definir como um switch processa pacotes
  - Especifica o pipeline de comutação
    - Em quais campos ele corresponde?
    - Que ações ele executa nos pacotes?
    - Em que ordem ele executa as partidas e ações
  - Especifique o comportamento de um dispositivo existente
  - Especifique uma abstração lógica para o dispositivo

- Tempo de execução P4
  - Uma API usada para controlar switches cujo comportamento já foi especificado no P4 linguagem
  - Funciona para diferentes tipos de interruptores
    - Fixo
    - Semiprogramável
    - Totalmente programável