2013中国教育和科研计算机网CERNET
第二十界学术年会暨会员代表大会

软件定义网SDN研究进展及清华大学的相关研究工作

毕军
清华大学
2013年10月15日

目　录

- 什么是SDN？以及个人的一些思考
- SDN的学术研究和标准化进展
- SDN与IPv6的关系及清华大学在SDN与开放式网络方面的研究工作

什么是SDN？

- SDN = Software Defined Networking
  - 太抽象了
- SDN = OpenFlow ？
  - 不完整

SDN定义-工业界

- ONS （open networking summit）Webpage 2013.4.15
  - http://opennetsummit.org/why-sdn.html

1. Difficult to optimize.
   Network operators are find
   optimize their expensive in
   networks.
2. Known problems.
   Networks continue to have
   mobility and evolvability th
3. Capital costs.
   Network capital costs have
   growing, putting excessive
4. Difficult to customize.
   Even vendors and third par
   address their customers' pr

- 现有网络存在的问题：
  - 难于优化：网络运营者发现对其昂贵的基础设施（数据中心、广域网、企业网）很难引入新的增值服务和优化
  - 已知问题：网络总是面临很多安全性、鲁棒性、可管理性、移动性、可演进性等难以解决的问题
  - 资本开销：设备开销和运行开销增长
  - 难于定制：对各户的需求难于定制化

SDN定义-工业界

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What is SDN? »

SDN is a disruptive technology that is making networks programmable by ordinary programmers using ordinary software running on ordinary operating systems in ordinary servers. With SDN, the introduction of new features becomes less manual, less prone to error, and faster to implement.

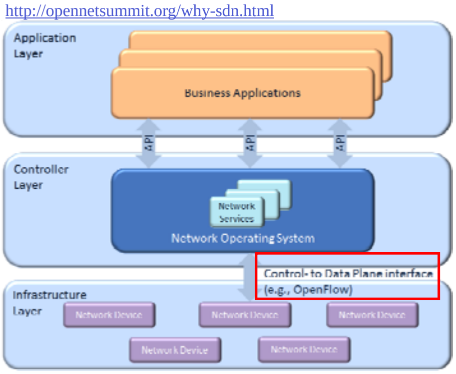
- SDN是一个颠覆性的技术，使普通程序员能使用普通软件运行在普通操作系统和普通操作系统上对网络进行编程
- SDN使引入新功能变得更少手工配置、更少错误、和更快实现

- SDN的核心属性包括：数据与控制平面分离；控制与数据平面之间采用统一的厂商无关的接口OpenFlow；逻辑上集中的控制平面为用户和运行者提供一致的、系统的可编程接口；对底层网络进行切片和虚拟化
- SDN使引入新功能变得更少手工配置、更少错误、和更快实现
- 逻辑上集中的控制平面由网络操作系统实现，为其上实现的服务或控制应用提供全网的逻辑地图
- SDN使网络运行者或第三方可以通过写简单的软件程序来引入新服务或定制网络行为，来控制网络的某个切片里的逻辑地图；其他对网络管控工作都交给网络操作系统

SDN's key attributes include: separation of data and control planes; a uniform vendor-agnostic interface called OpenFlow between control and data planes; a logically centralized control plane that offers a consistent, system-wide programming interface to users and operators; and slicing and virtualization of the underlying network. The logically centralized control plane is realized using a network operating system that constructs and presents a logical map of the entire network to services or control applications implemented on top of it. With SDN, a network operator or third party can introduce a new service or customize network behavior by writing a simple software program that manipulates the logical map of a slice of the network. The rest is taken care of by the network operating system.

SDN定义-工业界

- http://opennetsummit.org/why-sdn.html



SDN定义-国际标准组织

- **IRTF SDNRG Charter 2013.1.14**
  - http://irtf.org/sdnrg
  - SDN promises to provide a multi-layer platform which encompasses programability not only at the forwarding and control planes, but also at the transport layers below and orchestration and services layers above the data and control planes.
  - Early SDN models focused primarily on moving the control plane out of the network elements into "controllers" on the theory that the switching elements could remain simple, general-purpose, and cost-effective while at the same time allowing the control plane to rapidly evolve. A number of recent SDN models, on the other hand, include approaches in which control and data plane programability works in concert with existing and future distributed control planes.

SDN定义-学术界

- **ACM SIGCOMM HotSDN Workshop 2013.8.16**
  - Software Defined Networking (SDN) refactors the relationship between network devices and the software that controls them. Opening up the interfaces to programming network hardware enables more flexible and predictable network control, and makes it easier to extend the network with new functionality.
  - Many important research challenges remain:
    - How do we design switches and programming interfaces that offer greater flexibility without compromising performance?
    - How do we design software platforms for managing software defined networks?
    - How do we design new applications that capitalize on the programmability of the network?
    - How do we lower the barrier to creating, testing, and evaluating new applications?
    - How do we transition existing networks?
    - How can a software defined network interoperate with existing protocols and devices?

什么是SDN?

- “什么是SDN”目前还是一个未达成严格共识定义的问题
  - OpenFlow只是SDN在数据平面抽象的一个实例
  - SDN的深入研究还是“正在进行时”，处于百家争鸣、百花齐放阶段，给我们的研究空间还很大
  - SDN为什么热门，还是有“玄机”的，符合了人们一种期待

我个人对SDN的一点认识

- 我认为SDN是一种“元体系结构”(meta-architecture)
  - *Metadata* are data about data（who has produced them, when, what format the data are in and so on）
  - *Meta-language* is a sort of language for describing another language
  - SDN is a *meta-architecture* which is an architecture about architecture to describe or support another architecture
- 清华大学承担的国家863项目“未来网络体系结构和创新环境”的FINE体系结构的理论基础就是通过提供描述具体体系结构和协议的能力，来支撑网络新技术（包括IP和非IP）的研究、设计、试验、运行、创新、演进

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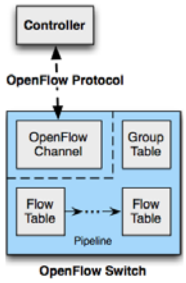
SDN引起了工业界和学术界的高度重视

- Ethane(2007) ->OpenFlow(2008)->SDN(2009/2010)
- 工业界
  - 2011年成立开放式网络基金会ONF（分水岭）
  - 2011年开始组织开放式网络峰会ONS年会, 以及欧洲、亚洲的各种类似会议，盛况空前
  - 国际标准研究组织IRTF于2012年10月成立了SDNRG研究组
  - 我国于2012年成立了中国SDN与开放式网络专委会，与ONF建立战略合作关系
  - 2013年4月厂商为主成立了Open Daylight Project (ODP)
- 学术界
  - 2012年顶级学术会议SIGCOMM成立HotSDN Workshop
  - 2013年开始一些著名国际会议开始将SDN纳入征稿的主题
  - 今年顶级国际学术会议SIGCOMM约1/5是SDN

SDN技术中成熟的工业标准OpenFlow



（1）设备的控制平面与数据平面分离

（2）协议运行在外部控制器上

（3）交换机抽象为多个流表的处理过程（Match+Action）

（4）外部协议通过控制器OpenFlow协议与设备交互

ONF的组织结构

- Extensibility WG
- Config & Management WG
- Testing & Interop WG
- ARCH & Framework WG & NBI WG
- Forwarding Abstractions WG
- Migration WG
- Wireless & Mobility WG
- Optical Transport WG
- Market Education WG
- Security DG
- 一年两次Member's Work Days

15

ONF的OpenFlow标准化进展

- OpenFlow 1.0.0 2009.12.31
  - 最主要特征: 12元组match (in_port + L2, L3, L4)+ 3类Action (forward, modify header, send to controller)，容易用现有硬件实现
  - OpenFlow 1.0.1 2012.6.7 OpenFlow 1.0.2 预计2013年11月
- OpenFlow 1.1.0 2011.02.28
  - 最主要特征: 多流表流水线 （与OF1.0不后向兼容）
- OpenFlow 1.2 2011年12月
  - 最主要特征: OXM灵活性 （基于OF1.1）
- OpenFlow 1.3.0 2012.06.25 （基于OF1.2和1.1）
  - Stable target for hardware vendors /long term support ONF Extensions for 1.3.X : new features （其他版本新功能将移入）
  - OpenFlow 1.3.1 2012.09.06 OpenFlow 1.3.2 2013.04.25
  - OpenFlow 1.3.3 预计2013年10月 OpenFlow 1.3.4 2014年初
- OpenFlow 1.4.0 2013.08.14 OpenFlow 1.4.1修改
- OpenFlow 1.5.0 2014年中-底 incremental improvement

ONF Members (*China*) as of August 22, 2013

- 6Wind
- A10 Networks
- Active Broadband
- ADVA Optical
- Alcatel-Lucent/Nuage
- *Alibaba*
- Aricent Group
- Arista
- *Beijing Internet Inst.*
- Big Switch Networks
- Broadcom
- Brocade
- *Centec Networks*
- Ceragon
- *China Mobile*
- Ciena
- Cisco
- Citrix
- CohesiveFT
- Colt
- Coriant
- Corsa Technology
- Cyan
- Dell/Force10
- Deutsche Telekom
- Ericsson
- ETRI
- Extreme Networks
- F5 / LineRate Systems
- Facebook
- *Fiberhome Technologies*
- Freescale Semi
- Fujitsu
- Gigamon
- Goldman Sachs
- Google
- Hitachi
- HP
- *Huawei*
- IBM
- Infinera
- Infoblox/FlowForwarding
- Intel
- Inst. for Info. Industry
- Intune Networks
- IP Infusion
- Ixia
- Juniper Networks
- KDDI
- Kemp Technologies
- Korea Telecom
- L-3 Comms-East
- Lancope
- Level3 Comms
- LSI
- Luxoft
- Marvell
- MediaTek
- Mellanox
- Metaswitch Networks
- Microsoft
- Midokura
- NCL Comms K.K.
- NEC
- Netgear
- Netronome
- Netscout Systems
- Nokia Siemens Netw.
- NoviFlow
- NTT Communications
- Optelian
- Oracle
- Orange
- Overture Networks
- Pica8
- Plexxi
- Procera Networks
- Qosmos
- Rackspace
- Radware
- Riverbed Technology
- Samsung
- SK Telecom
- Spirent
- Sunbay AG
- Swisscom
- Tail-f Systems
- Tallac
- Tekelec
- Telecom Italia
- Telefonica
- Tellabs
- *Tencent*
- Texas Instruments
- Thales
- Tilera
- TorreyPoint
- Transmode
- Turk Telecom/Argela
- TW Telecom
- Vello Systems
- Verisign
- Verizon
- Virtela
- VMware/Nicira
- Xpliant
- Yahoo!
- *ZTE*

SDN market projection – from ONF

ONF主席Dan Pitt: 到2014年底，将没有一个交换机端口不支持OpenFlow

– 全球SDN与开放式网络峰会发言

Source:

SDN的学术研究进展

❖体系结构
- Ethane: Taking Control of the Enterprise, SIGCOMM07
- OpenFlow: Enabling Innovation in Campus Networks, CCR08
- The Future of Networking, and the Past of Protocols, Scott Shenker's PPT at ONS11
- Software-Defined Internet Architecture: Decoupling Architecture from Infrastructure, HotNet12
- SDIA (SDN 2.0)

SDN的学术研究进展

❖控制器/控制平面的设计
- Onix: A Distributed Control Platform for Large-scale Production Networks, OSDI10
- Scalable Flow-based Networking with DIFANE, SIGCOMM10
- DevoFlow: Scaling Flow Management for High-performance Networks, SIGCOMM11

❖设备/数据平面的设计
- Forwarding Metamorphosis: Fast Programmable Match-Action Processing in Hardware for SDN, SIGCOMM13

SDN的学术研究进展

❖编程语言和抽象接口
- Abstractions for Network Update, SIGCOMM12 (Frenetic）
- Composing Software-Defined Networks, NSDI13
- Maple: Simplifying SDN Programming Using Algorithmic Policies, SIGCOMM13
- Participatory Networking: An API for Application Control of SDNs, SIGCOMM13

SDN的学术研究进展

❖测试、调试和管理
- A NICE Way to Test OpenFlow Applications, NSDI12
- A SOFT Way for OpenFlow Interoperability Testing, CoNEXT12
- Veriflow: Verifying Network-Wide Invariants in Real Time, Ahmed Khurshid, NSDI13
- Software Defined Traffic Measurement with OpenSketch, NSDI 13
- StEERING: A Software-Defined Networking for Inline Service Chaining, ICNP2013

SDN的学术研究进展

❖校园网的应用
- Can the Production Network Be the Testbed?, OSDI10

❖网络安全的应用
- FRESCO: Modular Composable Security Services for Software-Defined Networks, NDSS13

❖MiddleBox的应用
- SIMPLE-fying Middlebox Policy Enforcement Using SDN, SIGCOMM13

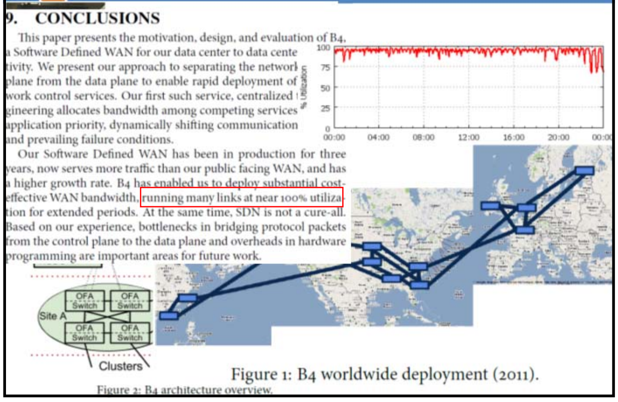
❖私有WAN的应用
- B4: Experience with a Globally-Deployed Software Defined WAN, SIGCOMM13
- Achieving High Utilization with Software-Driven WAN, SIGCOMM13

SDN的学术研究进展

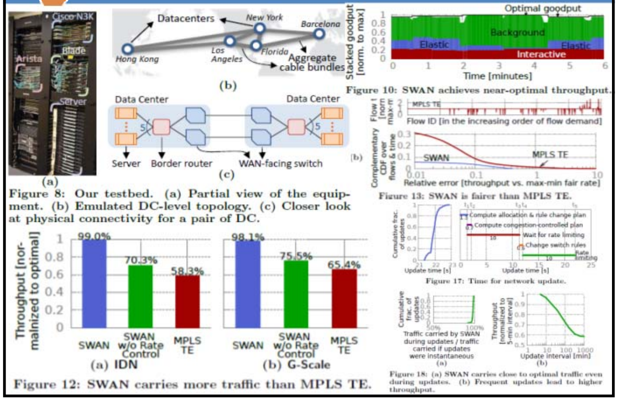
❖数据中心的应用
- Hedera: Dynamic Flow Scheduling for Data Center Networks, NSDI10
- ElasticTree: Saving Energy in Data Center Networks, NSDI10
- ServerSwitch: A Programmable and High Performance Platform for Data Center Networks, NSDI11
- zUpdate: Updating Data Center Networks with Zero Los, SIGCOMM13
- ElasticSwitch: Practical Work-Conserving Bandwidth Guarantees for Cloud Computing, SIGCOMM13

❖视频的应用
- ❖ OpenSession: SDN-based Cross-layer Multi-stream Management Protocol for 3D Teleimmersion, ICNP2013

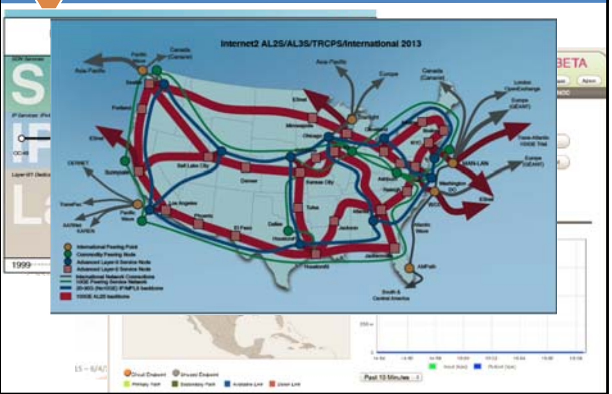
SDN的应用-Google Private WAN



SDN的应用：Microsoft Private WAN



SDN的应用-Internet2



个人观点：SDN的未来研究挑战

- 体系结构
  - 体系结构的理论问题
  - SDN的定义是值得深入研究的
- 控制平面扩展性
  - 集中管控的天然局限性
  - 多控制器、分布式控制器、数据平面方案减压
  - 东西向接口的跨域扩展
- 数据平面能力
  - OpenFlow表述能力的扩展
  - 呼唤新的硬件结构

个人观点:SDN的未来研究挑战

- 安全研究的成果不多
  - 抵御DOS攻击
- 编程语言和接口
  - 应该是体现SDN特色的最重要方面
  - 网络运营者的思维转换需要一个过程
    - 互联网公司可能比传统运营者如运营商更能接受，因为传统方式已经不堪重负，需要求变
- 实际应用！
  - 实际应用案例非常重要

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为什么SDN与IPv6是支持和被支持的关系?

- SDN与具体网络体系结构的关系
  - 回到我的个人观点: SDN是一种“元体系结构”(meta-architecture)
  - SDN有描述其他体系结构或协议的能力，也具有描述IPv6的能力
  - SDN可被认为是工具层面的技术，脱离了具体的被描述对象，SDN没有任何意义
- 应按照这个思路是理解、研究和设计SDN
  - 不同人设计出的SDN是不同，是因为描述能力的不同

SDN支持IPv6的研究和试验

- 基于SDN的域内IPv6源地址验证
- 基于SDN的接入网IPv6源地址验证SAVI
- 基于SDN的IPv6过渡技术

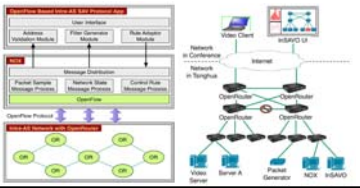
清华大学2010年即开始SDN与IPv6结合工作

- **Tsinghua-Stanford University于2010年签署研究合作协议**
  - OpenFlow Extension for IPv6, SAV, etc.
  - Reference implementation, deployment
  - Academic visiting and joint training students

基于SDN的域内源地址验证在INFOCOM12演示

❖ **InSAVO: Intra-AS IPv6 Source Address Validation Solution with OpenRouter**

- **集中管控**：基于OpenFlow+提供的集中管控，上层应用可计算得到全局转发路径，进而可消除传统分布式计算下不对称路由造成的假阳性误过滤问题
- **集成协议**：通过统一的OpenFlow扩展协议，来统一SNMP/xFlow/Telnet等多种管控协议，以降低多种控制接口造成的复杂度
- **可增量部署**:通过现网设备升级和扩展OpenFlow能力，实现可增量的实际部署

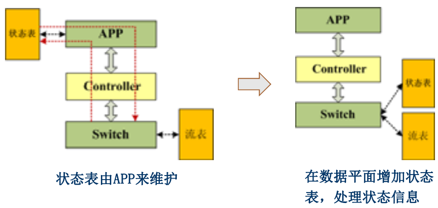


Software Defined SAVI (SDN-SAVI)

- 基本思想：将复杂性交给控制器处理
  - 地址分配方式的复杂性
  - 场景的复杂性（例如移动等）
  - 新的IPv6技术不断出现如何去兼容

基于SDN的IPv6过渡究和试验

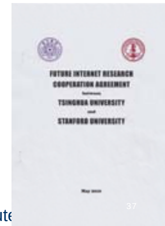
- SDN支持IPv4/IPv6过渡



❖ 通过在SDN带状态的数据平面转发抽象技术，在开放式网络设备内维护和处理IPv4/IPv6地址的映射表等状态信息，提高转发性能

Joint SDN Research

- **Tsinghua-Stanford University (Since 2010)**
  - OpenFlow Extension for IPv6, SAV, etc.
  - Reference implementation, deployment
  - Academic visiting and joint training students
- **CERNET-INTERNET2 (Since 2012)**
  - Inter-domain SDN (to demo in Sep. 2013)
- **Tsinghua-Huawei (Since 2011)**
  - OpenFlow for IPv6 and IPv6/IPv4 translation
  - West-east interfaces/ Data Center
- **Tsinghua-ZTE (Since 2011)**
  - FlowTable salability and performance evaluation
- **Tsinghua-HP (Since 2011)**
  - Scalable distributed control in open networking
- **Tsinghua-DCN (Since 2011)**
  - OpenRouter: OpenFlow+ upgradion for legacy route



SDN Research @ Tsinghua

- **Network Architecture**
  - *FINE*: Future network INnovation Environment
  - Theoretical model
- **OpenFlow Extension**
  - *OpenFlow+:* OpenFlow extension for new forwarding abstract; protocol independent (IPv6, etc.) and network status awareness
  - New Forwarding Abstractions for stateful data plan
- **Dataplan/New Device (collaborating with domestic vendors)**
  - *OpenRouter:* OpenFlow+ upgradion based on a legacy router
  - Virtual Forwarding Plan
- **Controller**
  - Scalability of Controller/Distributed Controller （performance/failure)
  - WEBridge: West-East Bridge

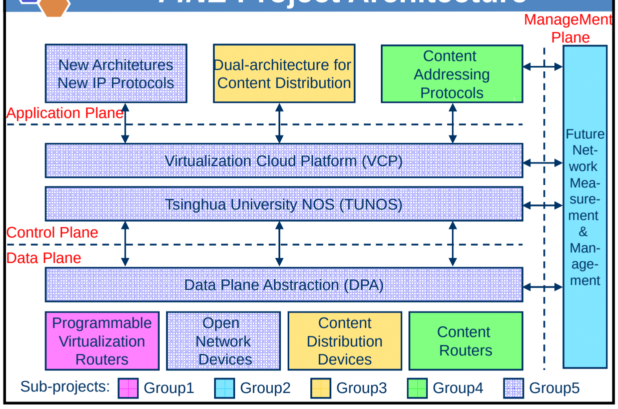
SDN Research @ Tsinghua

- **Testing**
  - OpenFlow Switch conformance testing
  - OpenFlow Controller performance testing
- **Applications**
  - IPv6 Intra-AS Source Address Validation (SAV)
  - Inter-domain/Intra-domianTraffic Engineering + Fast Reroute
  - Data Center
  - IPv6/IPv4 translation
- **Testbeds**
  - OpenFlow Testbed:
    - OpenRouters, NetFPGA cards, OpenFlow switches (Huawei, H3C, DigitalChina, Dell), and software OpenFlow switches
    - Floodlight, NOX, Ryu, SOX, *TUNOS, ONOS*
  - Building a large-scale SDN network – for “863” FINE project

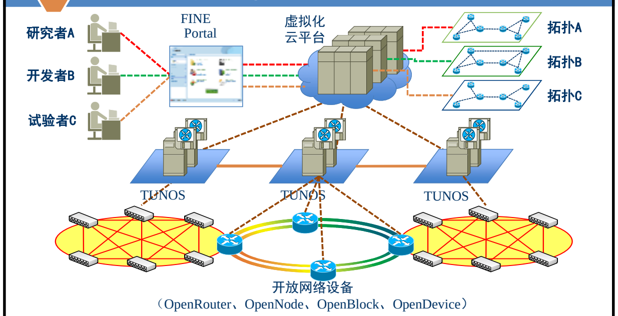
FINE项目简介

- ❖ 国家“863”项目：未来网络体系结构和创新环境（FINE）
- ❖ 主要参加单位：
  - 清华大学（牵头）、中科院计算所、北邮、东南大学、北京大学
  - 工信部电信研究院、解放军信大、国防科大等科研院校和中兴、华为、华三、神州数码、锐捷等网络设备厂商，并依托各高校、电信研究院、上海宽带、总参61所、中国移动研究院等建设试验平台
- ❖ 项目意义：
  - 新型网络体系结构和新型网络协议在设计方法、编址方式、转发机制、控制模式等方面存在巨大差异
  - 当前网络设备和试验环境的封闭性又严重制约着网络的技术创新和体系演进
  - 因此，设计和实现促进未来网络体系结构创新的环境，对支撑未来网络的技术创新和体系演进具有重要的意义

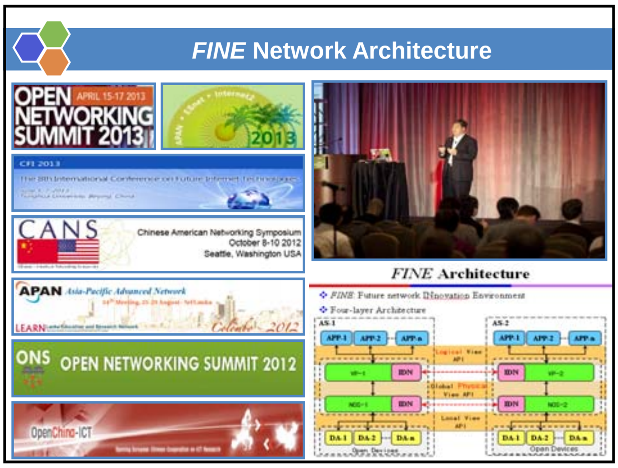
FINE Project Architecture

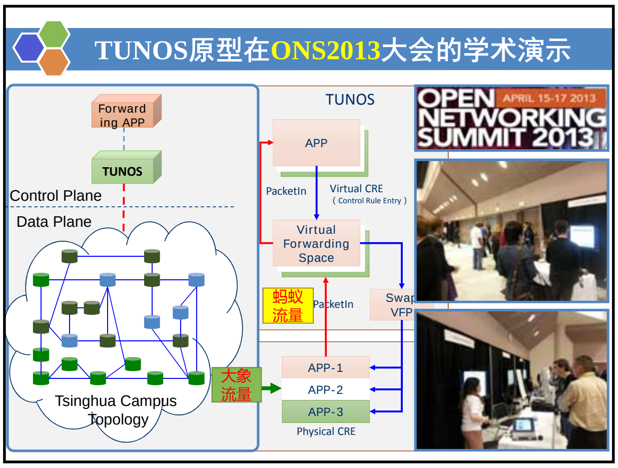


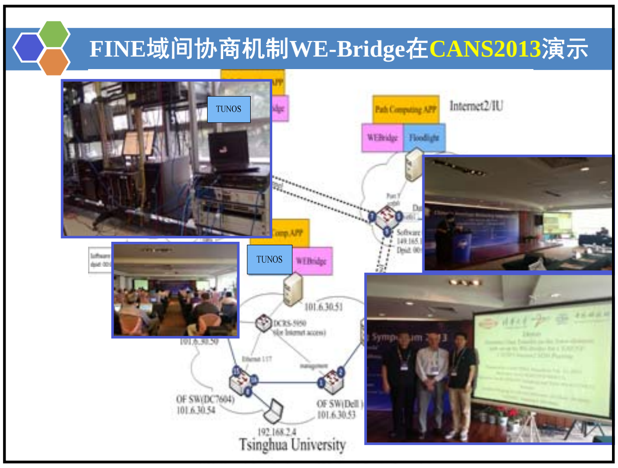
项目创新网络试验平台提供试验服务

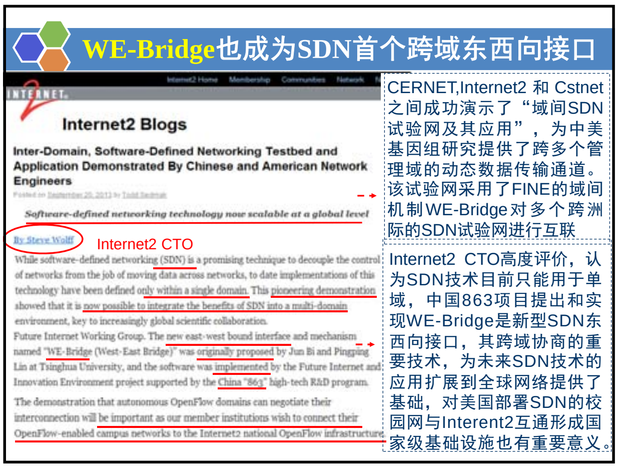


通过FINE试验平台，不同的试验者通过虚拟化云平台开发新体系和新协议，构建试验所需的特定虚拟网络环境。通过网域操作系统，控制不同开放网络设备实现不同数据平面的需要









结束语

- SDN的严格定义仍然有争议，我个人倾向认为SDN是一种提供描述其他体系结构能力的“元体系结构”，对构建网络科学有一定意义
- SDN已经引起了工业界和学术界的广泛关注，标准化和学术研究进展迅速
- SDN与IPv6不是对立的关系，是支持与被支持的关系
- 清华大学近年在SDN领域做了一些研究和探索

谢 谢！

敬请各位专家批评指正！