Software Defined Network
(SDN)

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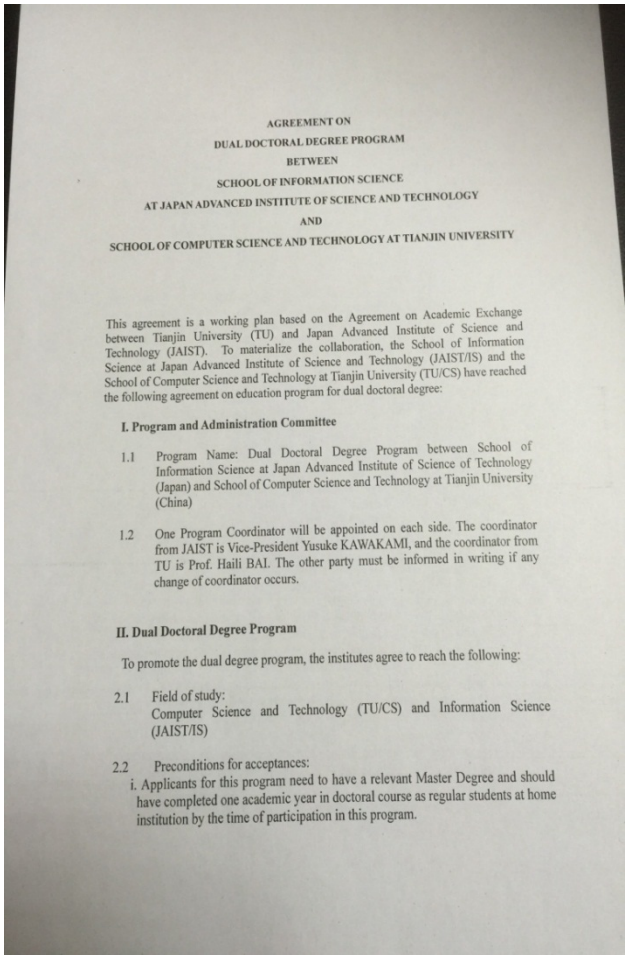
Dalian University of Technology
November 2015

Cooperation with JAIST

Dual-Doctoral Degree Program between JAIST/IS and TU/CS	➢Negotiation starting from the end of 2010 ➢Agreement signing in Dec. 2012
Dual –Master Degree Program between JAIST/IS and TU/SS & TU/CS	➢Agreement signing in Sep. 2014
Dual –Master Degree Program between JAIST/IS and TU/SS & TU/CS	➢Prof. Xiaohong Li and Prof. Baolin Liu from TU/CS ➢Prof. Jiawan Zhang from TU/SS

Cooperation with JAIST



AGREEMENT ON
DUAL DOCTORAL DEGREE PROGRAM
BETWEEN
SCHOOL OF INFORMATION SCIENCE
AT JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY
AND
SCHOOL OF COMPUTER SCIENCE AND TECHNOLOGY AT TIANJIN UNIVERSITY

This agreement is a working plan based on the Agreement on Academic Exchange between Tianjin University (TU) and Japan Advanced Institute of Science and Technology (JAIST). To materialize the collaboration, the School of Information Science at Japan Advanced Institute of Science and Technology (JAIST/IS) and the School of Computer Science and Technology at Tianjin University (TU/CS) have reached the following agreement on education program for dual doctoral degree:

I. Program and Administration Committee

1.1 Program Name: Dual Doctoral Degree Program between School of Information Science at Japan Advanced Institute of Science of Technology (Japan) and School of Computer Science and Technology at Tianjin University (China)

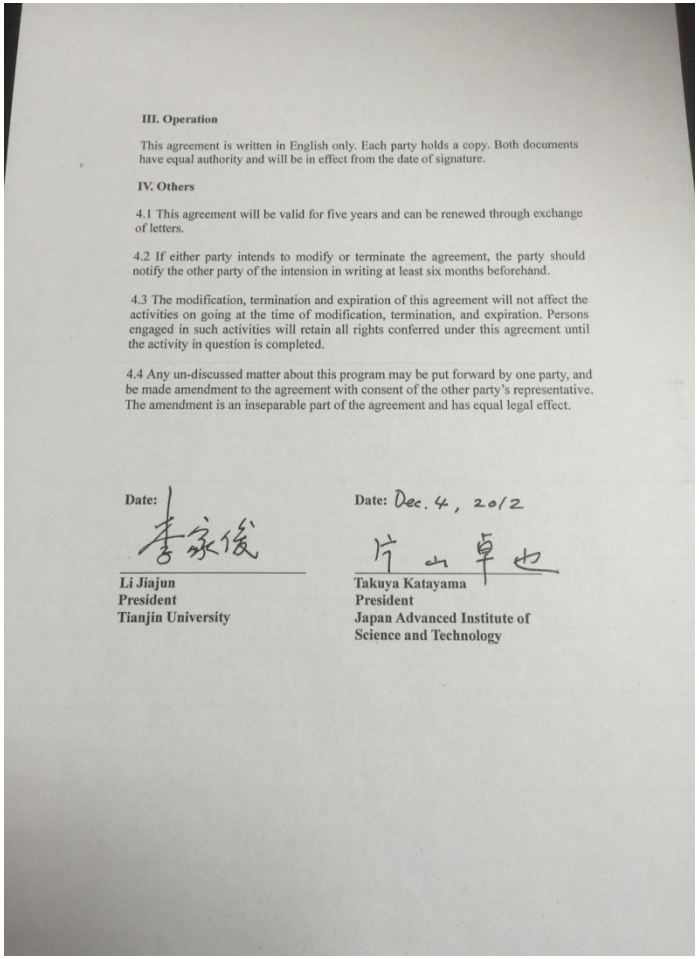
1.2 One Program Coordinator will be appointed on each side. The coordinator from JAIST is Vice-President Yusuke KAWAKAMI, and the coordinator from TU is Prof. Haili BAI. The other party must be informed in writing if any change of coordinator occurs.

II. Dual Doctoral Degree Program

To promote the dual degree program, the institutes agree to reach the following:

2.1 Field of study:
Computer Science and Technology (TU/CS) and Information Science (JAIST/IS)

2.2 Preconditions for acceptances:
i. Applicants for this program need to have a relevant Master Degree and should have completed one academic year in doctoral course as regular students at home institution by the time of participation in this program.



III. Operation

This agreement is written in English only. Each party holds a copy. Both documents have equal authority and will be in effect from the date of signature.

IV. Others

4.1 This agreement will be valid for five years and can be renewed through exchange of letters.

4.2 If either party intends to modify or terminate the agreement, the party should notify the other party of the intension in writing at least six months beforehand.

4.3 The modification, termination and expiration of this agreement will not affect the activities on going at the time of modification, termination, and expiration. Persons engaged in such activities will retain all rights conferred under this agreement until the activity in question is completed.

4.4 Any un-discussed matter about this program may be put forward by one party, and be made amendment to the agreement with consent of the other party's representative. The amendment is an inseparable part of the agreement and has equal legal effect.

Date:

Li Jiajun
President
Tianjin University

Date: Dec. 4, 2012

Takuya Katayama
President
Japan Advanced Institute of Science and Technology

Cooperation with JAIST

Reciprocal visits with Japan Advanced Institute of Science and Technology (JAIST) reciprocal visits

A group of 10 Ph.D. candidates visited JAIST in the summer vacation of 2011 to carry on academic exchange.

6 Faculty members are from JAIST!

1 Future Internet

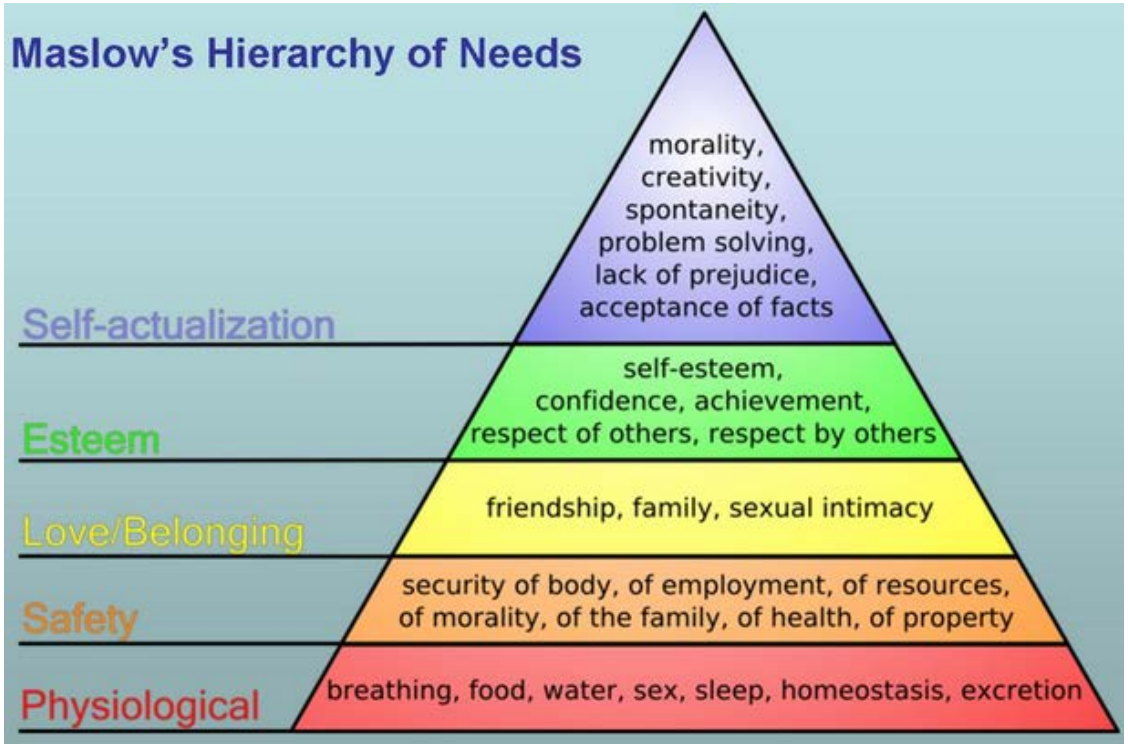
A. Current Internet

B. Future Internet Projects

C. The Motivation of SDN

Internet is Part of Life

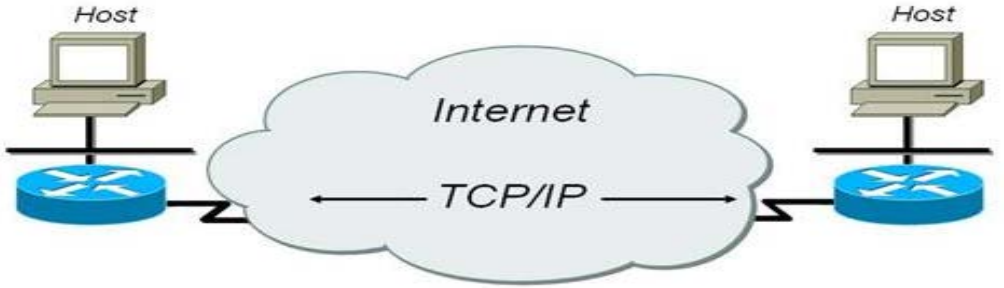
1 of every 3 end users believes the Internet is as important as air, water, food and shelter. They could not live without it.



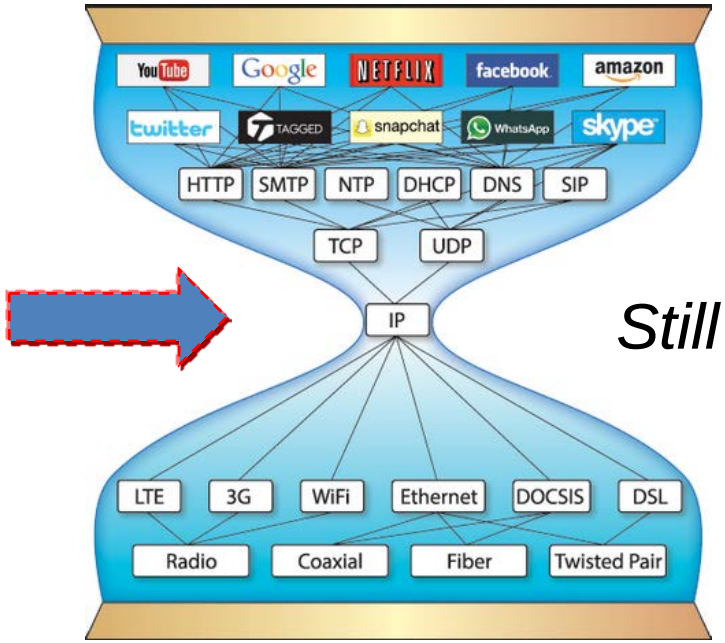
Internet

Current Internet

The current Internet was designed over 40 years ago with certain design principles



OSI Reference Model	TCP/IP
Application	Application
Presentation	
Session	
Transport	Transport
Network	Internet
Data Link	Network Interface
Physical	



Still TCP/IP

Drawbacks of Internet

1. The lack of security embedded in the original architecture.

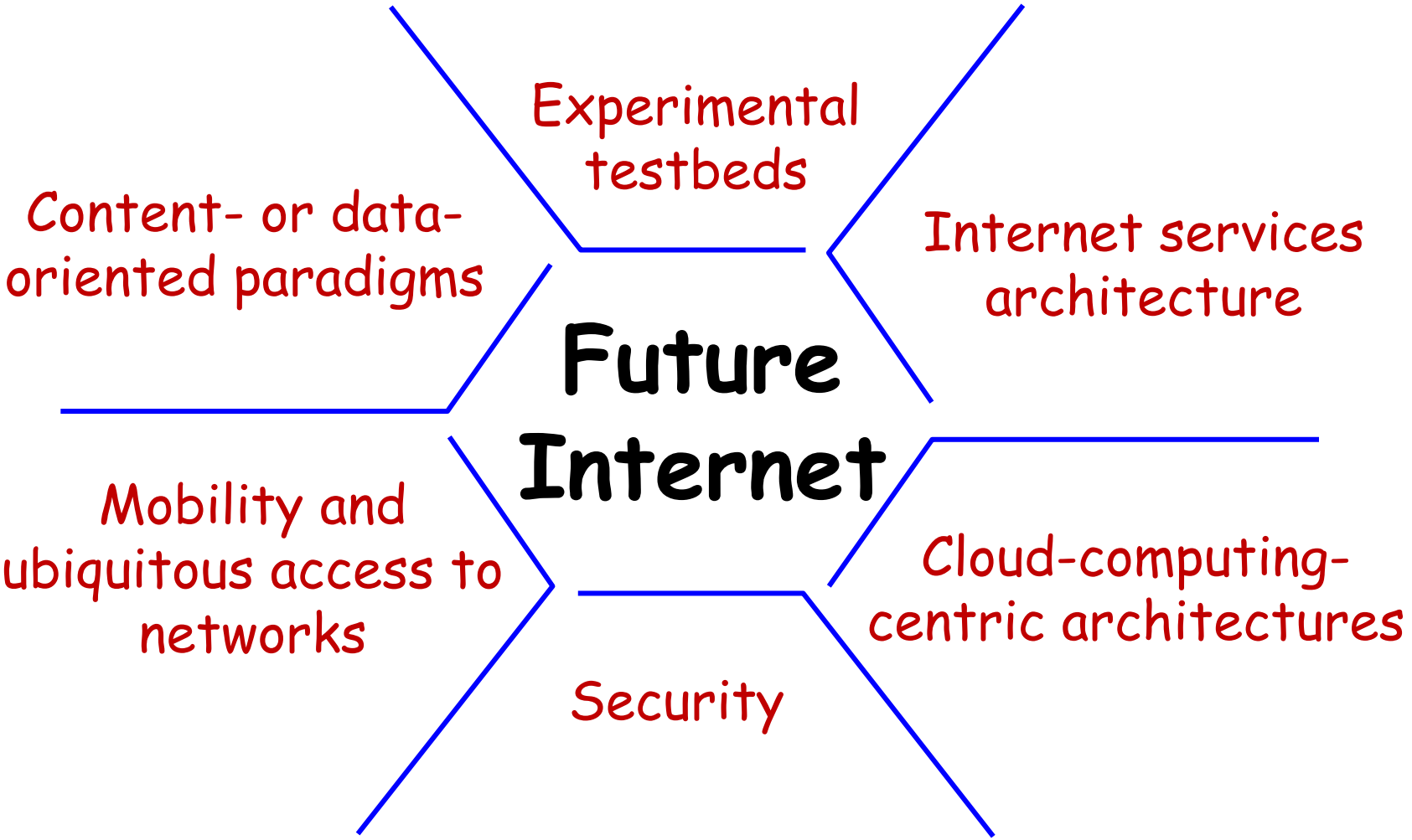
2. The core architecture is hard to modify.

Drawbacks

3. New functions have to be implemented through myopic and clumsy on top of the existing architecture.

4. Difficult to support the increasing demands through incremental changes.

Research Topics



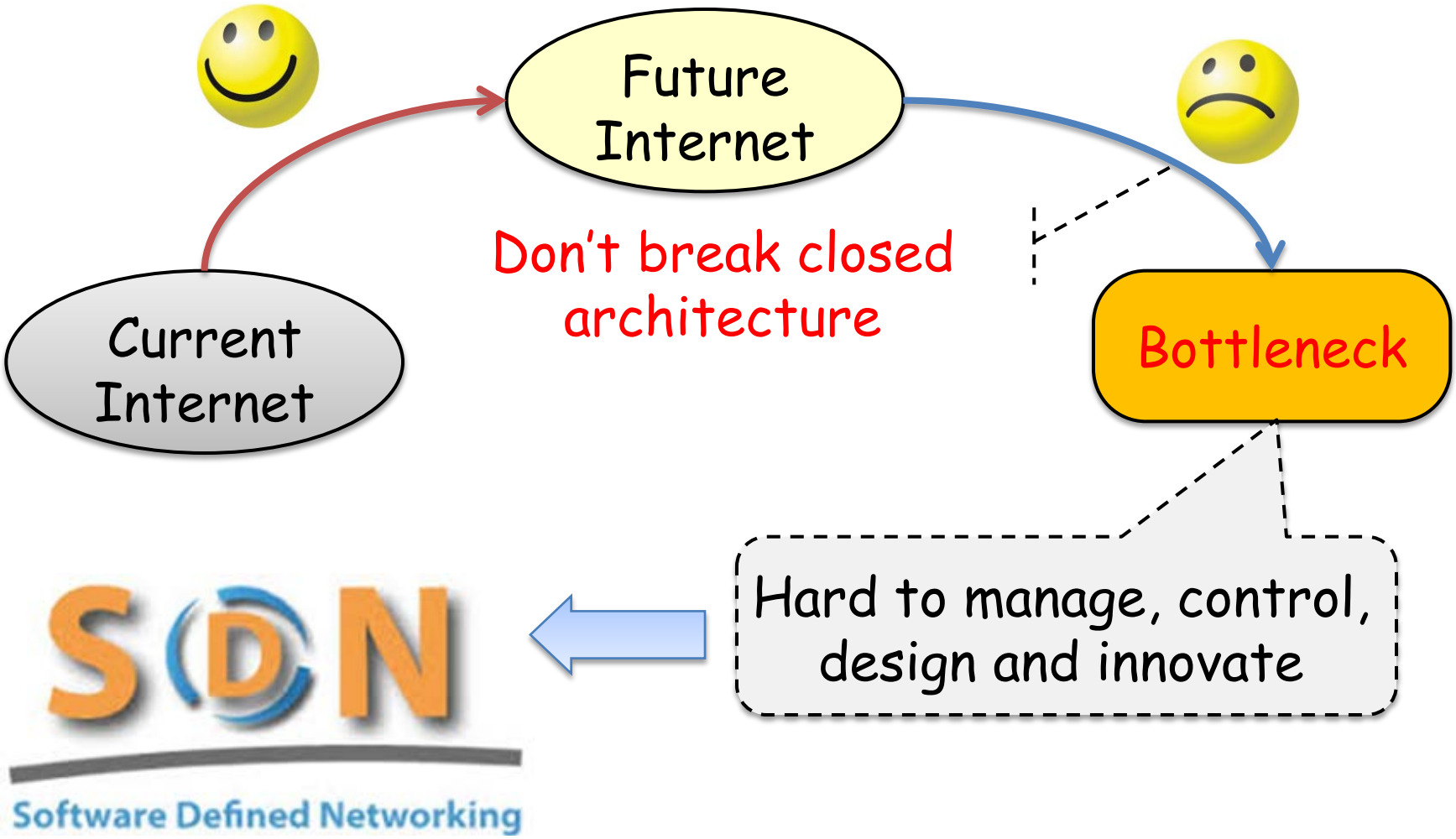
Future Internet Project

Categories	Project or cluster names (selected)
FIA	NDN, MobilityFirst, NEBULA, XIA, etc.
FIND	CABO, DAMS, Maestro, NetSerV, RNA, SISS, etc. (more than 47 total)
GENI	Spiral1: (5 clusters totally): DETER (1 project), PlanetLab (7 projects), ProtoGENI (5 projects), ORCA (4 projects), ORBIT (2 projects; 8 not classified; 2 analysis projects
	Spiral2: over 60 active projects as of 2009*
	Spiral3: about 100 active projects as of 2011*

* GENI design and prototyping projects can last for more than one spiral.

- Jianli Pan, Subharthi Paul, and Raj Jain. A Survey of the Research on Future Internet Architectures. IEEE Communications Magazine, July, 2011.

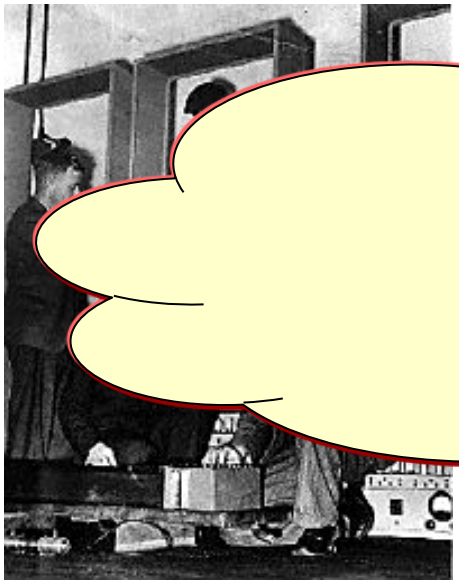
SDN is An Important Topic



The Motivation of SDN

- Development of Computer

Wilkes with the EDSAC, 1949



Hardware/Software Separation

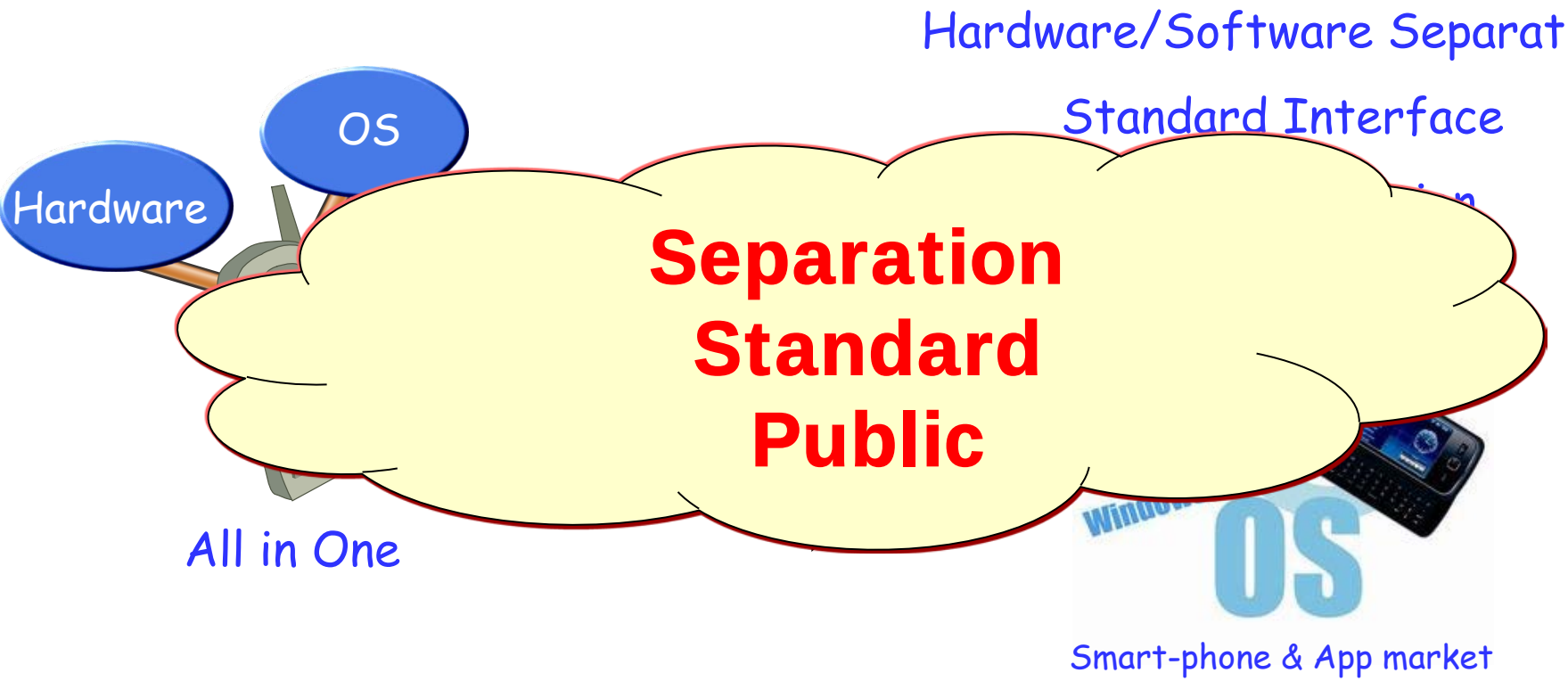
Standard Interface

Separation
Standard
Public

Personal Computer

The Motivation of SDN

- Development of Mobile Phone



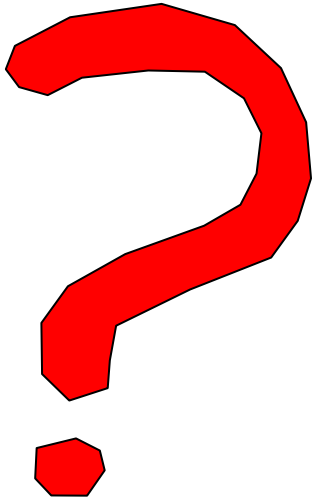
The Motivation of SDN

- Development of Networking Device

Black box
Inflexible
Difficult to operate

Hinder Development

How to develop

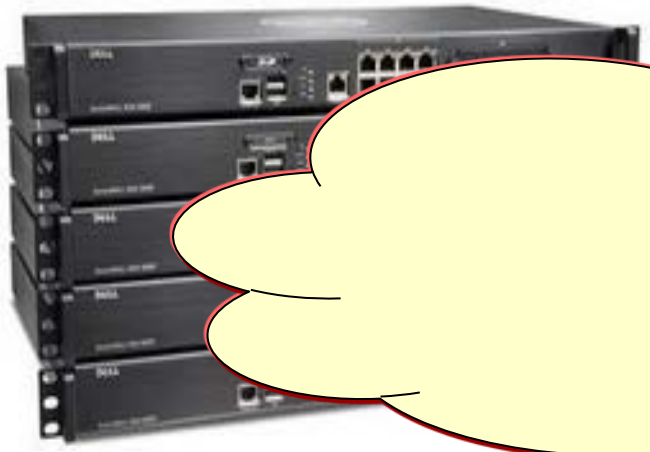


The Motivation of SDN

- Development of Networking Device

Hardware/Software Separation

Standard Interface



Separation
Standard
Public

Black box
Inflexible
Difficult to operate

SDN
Software Defined Networking

1 SDN Introduction

A. What is SDN?

B. Why do SDN?

C. State of the Art

An Innovation from Stanford

Stanford University


Martin Casado


Nick McKeown

In 2006, OpenFlow is proposed, which provides an open protocol to program the flow-table in different switches and routers. People can try new routing protocols and security models by a controller.

nicira

In 2007, Nicira is founded by Martin Casado, Nick McKeown and Scott Shenker. This company focuses on software defined networking and network virtualization. The aim is "Network is programmable"

acm sigcomm

IEEE INFOCOM

In 2008, one SIGCOMM paper :

McKeown N, Anderson T, et al. OpenFlow: enabling innovation in campus networks[J]. ACM SIGCOMM Computer Communication Review, 2008.

In 2009, INFOCOM Keynote :

McKeown N, Software-defined Networking

The Definition of SDN

Software-Defined Networking (SDN) is an **emerging architecture** that is **dynamic**, **manageable**, **cost-effective**, and **adaptable**, making it ideal for the high-bandwidth, dynamic nature of today's applications. This architecture **decouples** the network control and forwarding functions enabling the network control to become directly **programmable** and the underlying infrastructure to be **abstracted** for applications and network services.

The Definition of SDN

emerging architecture; dynamic; manageable; cost-effective; adaptable; decouples; programmable; abstracted.

Software-defined networking (SDN) is an **approach to computer networking** which evolved from work done at UC Berkeley and Stanford University around 2008. SDN allows network administrators to manage network services through **abstraction of lower level functionality**. This is done by **decoupling** the system that makes decisions about where traffic is sent (the control plane) from the underlying systems that forward traffic to the selected destination (the data plane). The inventors and vendors of these systems claim that this **simplifies networking**.

The Definition of SDN

OPEN NETWORKING FOUNDATION

emerging architecture; dynamic; manageable; cost-effective; adaptable; decouples; programmable; abstracted.

WIKIPEDIA
The Free Encyclopedia

approach to computer networking; abstraction of lower level functionality; decoupling; simplifies networking.

Gartner

Software-defined networks are **emerging networking architectures** that **separate** the **control plane** from the **data plane** in networking equipment. This is so that network intelligence and state are logically **centralized**, and the underlying network infrastructure is **abstracted** from applications.

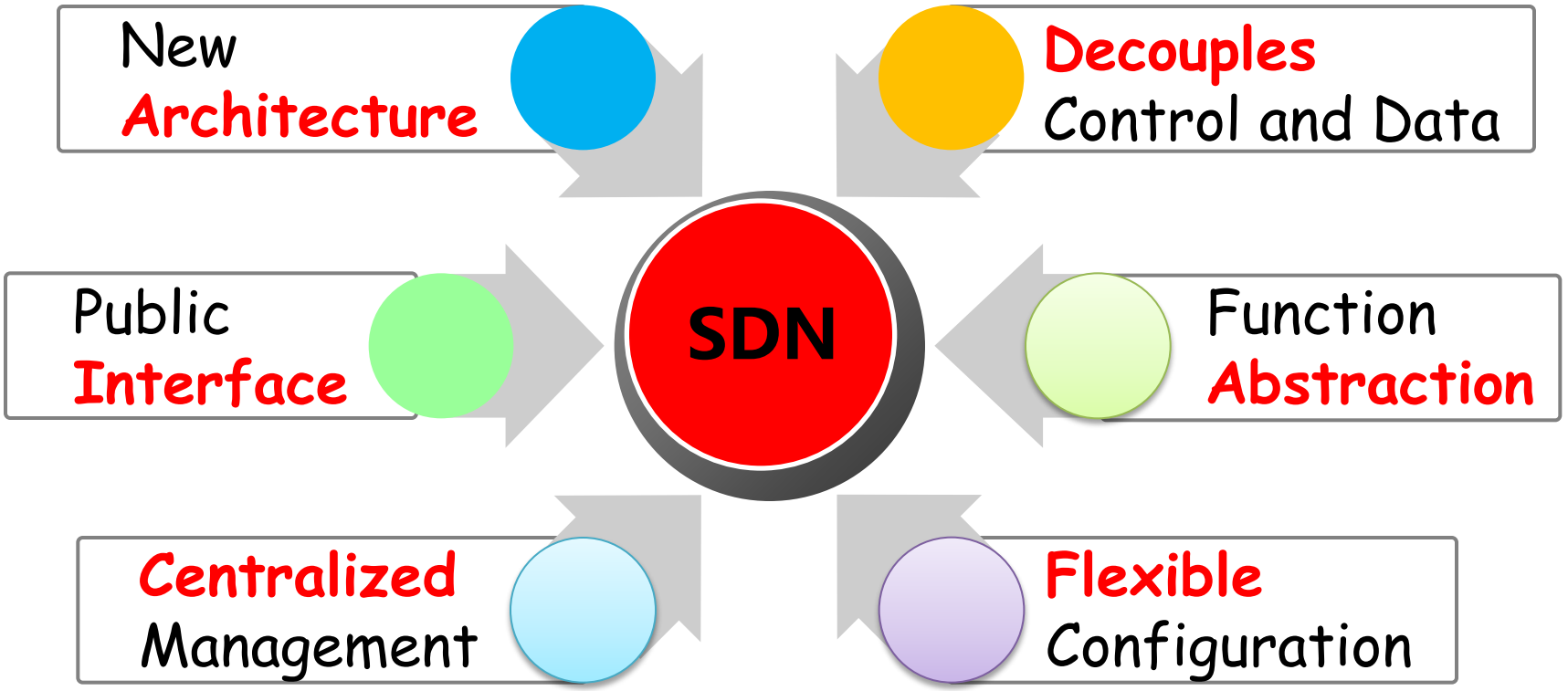
The Definition of SDN

emerging architecture; dynamic; manageable; cost-effective; adaptable; decouples; programmable; abstracted.

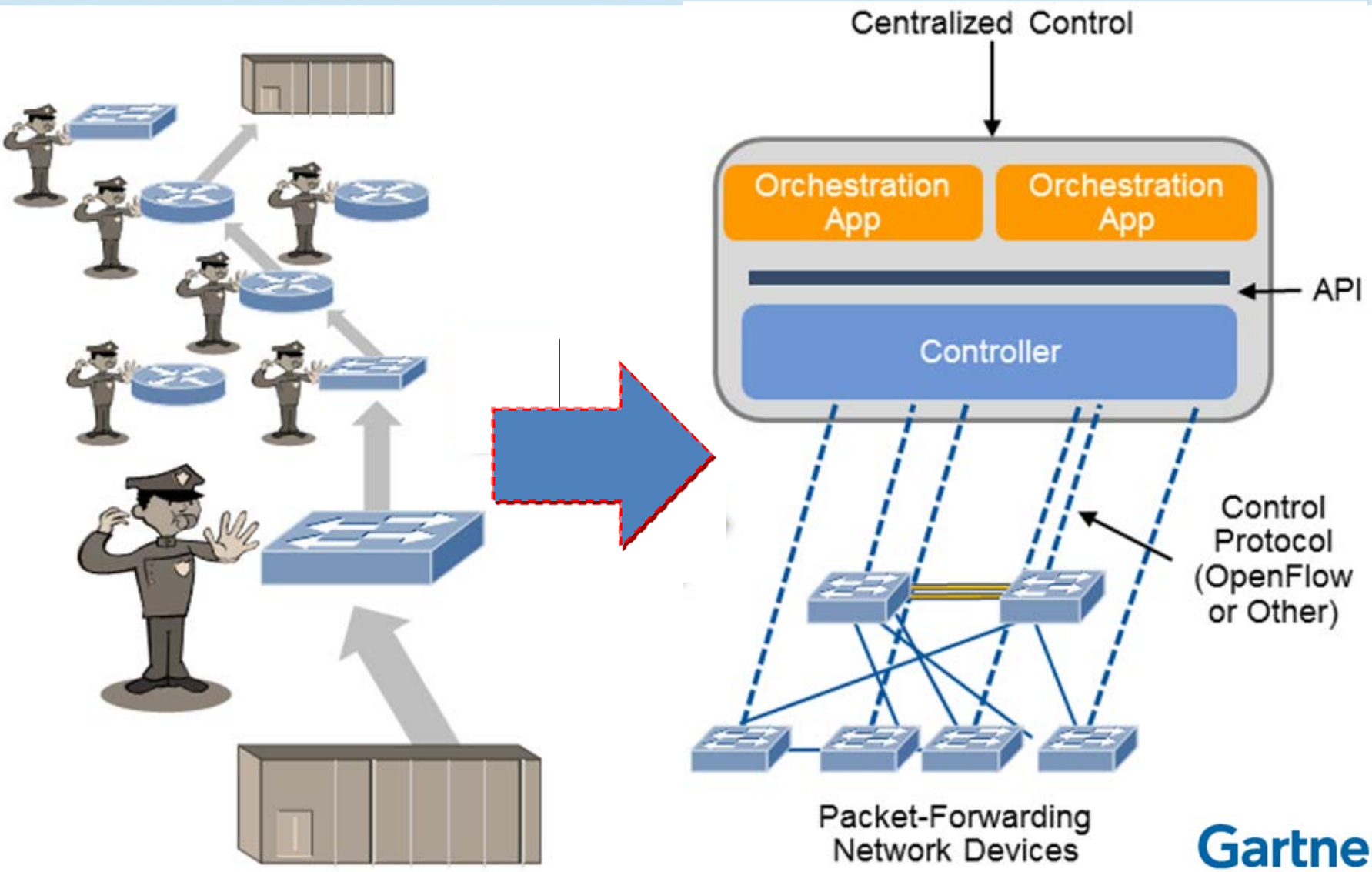
approach to computer networking; abstraction of lower level functionality; decoupling; simplifies networking.

emerging networking architectures; separate; control plane; data plane; centralized; abstracted.

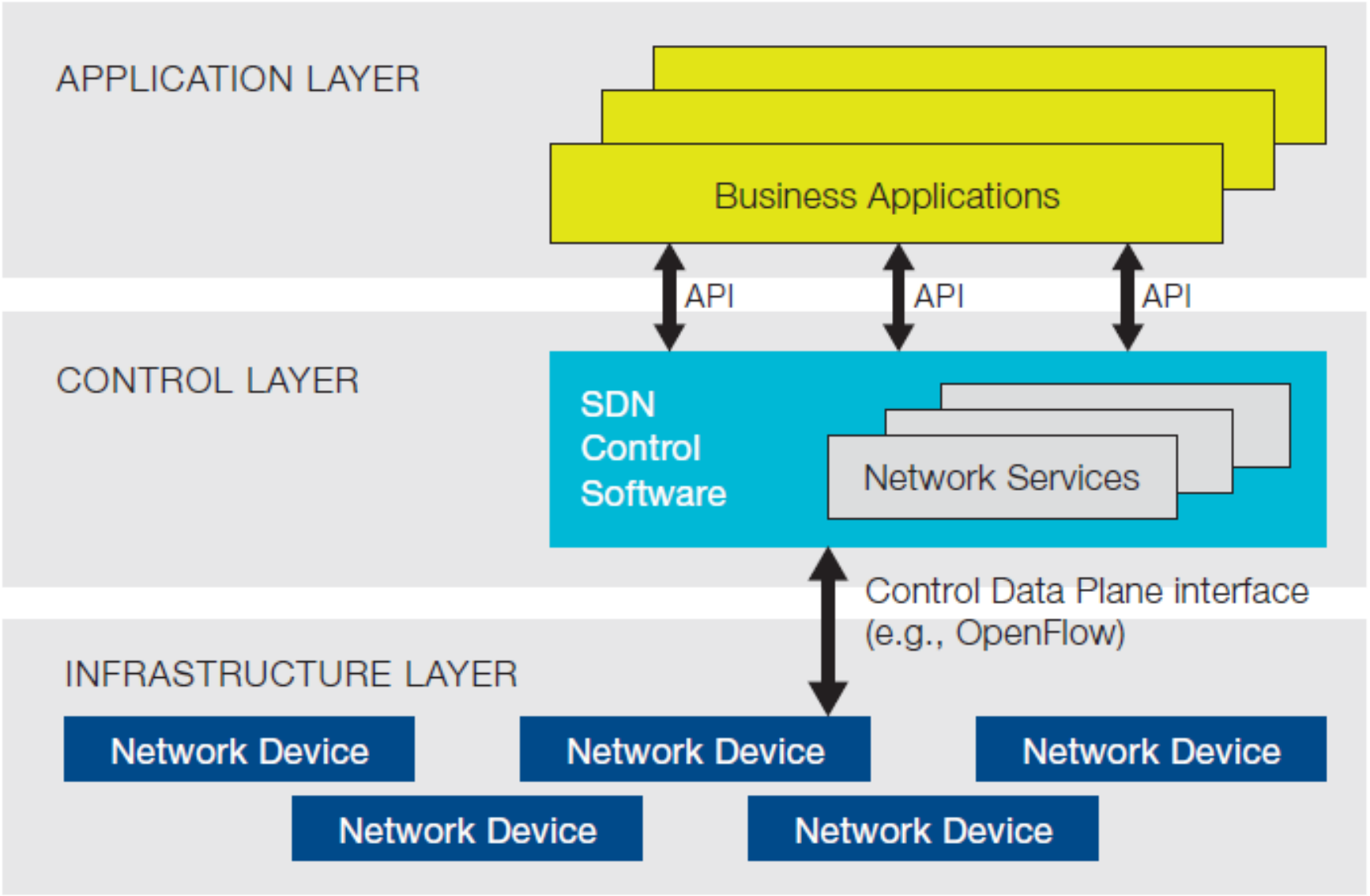
In My Opinion



SDN Illustration

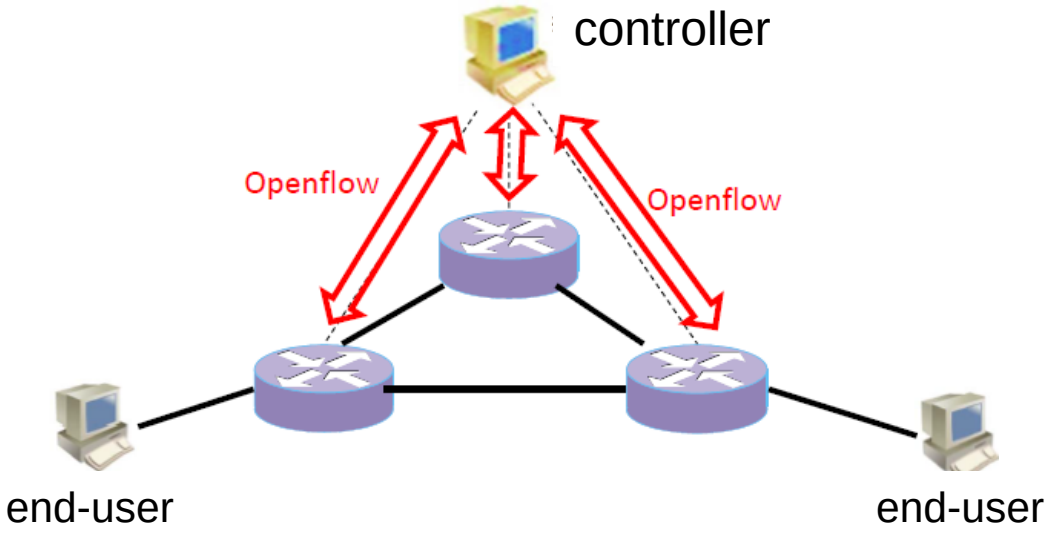


The Architecture of SDN



What is OpenFlow

OpenFlow ≠ SDN ⟶ OpenFlow ∈ SDN



OpenFlow is the first standard communications interface defined between the control and forwarding layers of an SDN architecture.

Why do SDN: Focus & Valuable

Industry

- 2011 Open Network Foundation (ONF)
- 2011 The First Open Networking Summit
- 2012 IRTF SDN Research Group (SDNRG)
- 2012 China SDN & Open Networking Summit

Academia

- SIGCOMM HotSDN Workshop
- Top Conference CFP including SDN
- Many National Funding for SDN Research

SIGCOMM CHICAGO 2014

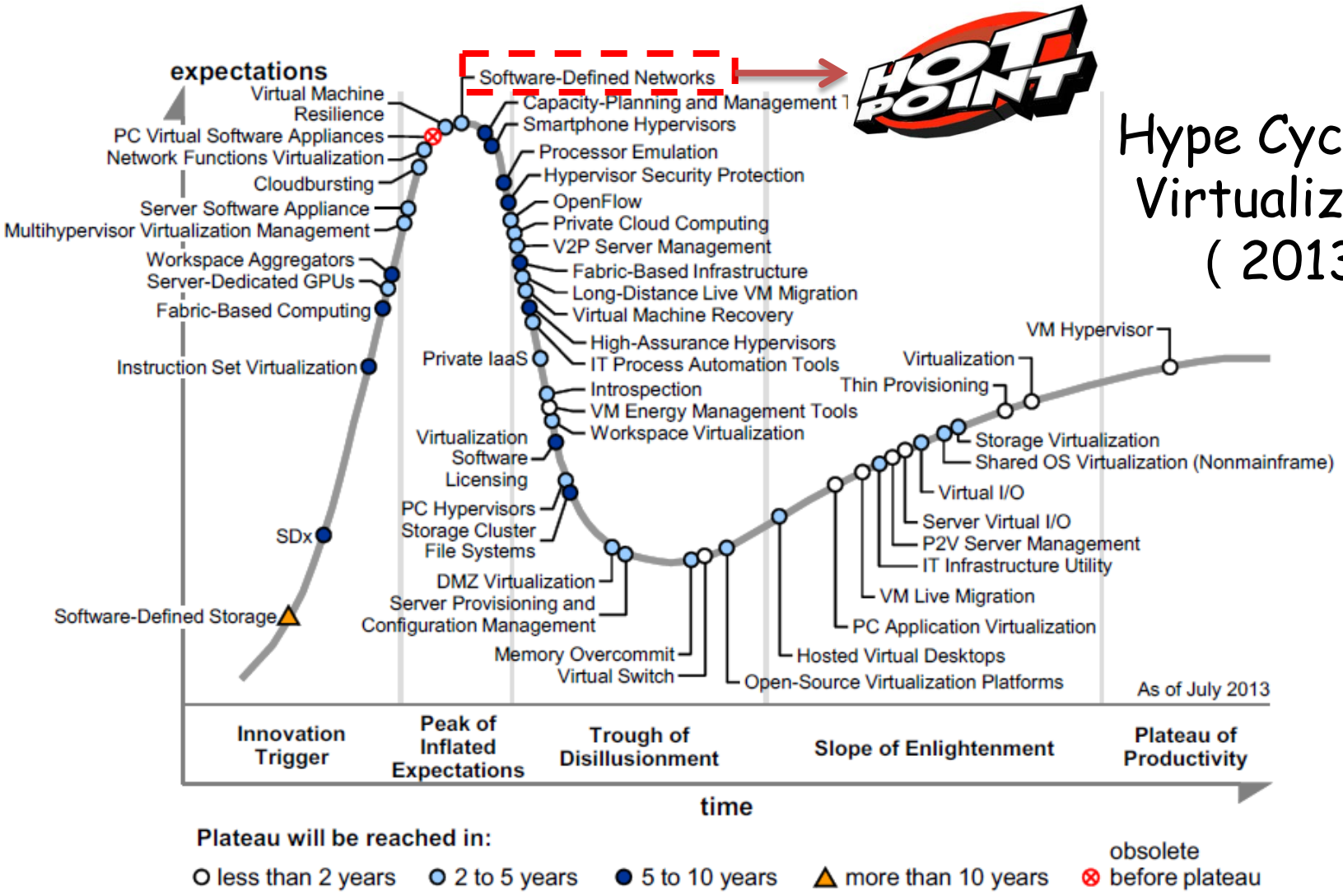
ACM SIGCOMM Workshop on Hot Topics in Software Defined Networking (HotSDN 2014)

Commerce

- VMware acquired Nicira for $1.26 billion
- Cisco acquired Cariden for $141 million
- IDC: SDN Market Forecast at $3.7 Billion by 2016

nicira vmware

Why do SDN: Reach the Peak



Hype Cycle for Virtualization (2013)

Source: Gartner (July 2013)

SDN in Industry

Open Networking Foundation

One public SDN platform is built by IBM, Cisco, Microsoft and others

Infonetics said "SDN market could hit $18B by 2018"

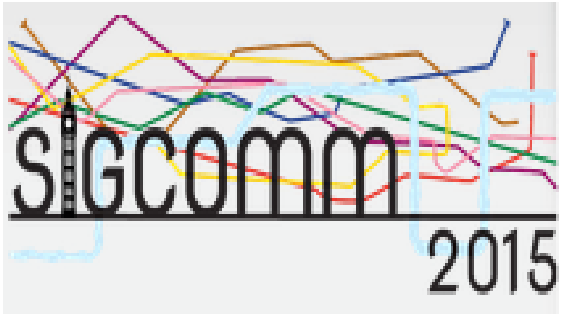
Openflow 1.0

Google's SDN solution B4 is successful

AT&T expands SDN based "Network on Demand" services to more than 100 cities.

SDN in Academia

Hot Topics in SIGCOMM



Best Paper Award :

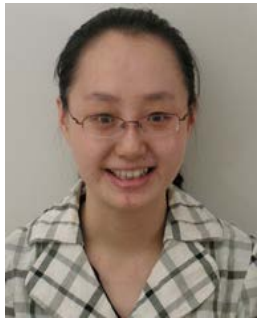
Stefano Vissicchio, Olivier Tilmans, Laurent Vanbever, Jennifer Rexford, "Central Control Over Distributed Routing"

Test of Time Paper Award :

Albert Greenberg, Gisli Hjalmtysson, et.al. "A Clean Slate 4D Approach to Network Control and Management"

Nick McKeown
SIGCOMM 2012 Award for Lifetime Contribution

Nick Feamster
SIGCOMM 2010 Rising Star Award



Minlan Yu
SIGCOMM 2011 Doctoral Dissertation Award

State of the Art

- **Architecture**
  - A Highly Available Software Defined Fabric, **HotNets 2014**
  - On the Scalability of Software-Defined Networking, **IEEE Communications Magazine 2013**
  - Fabric: A Retrospective on Evolving SDN , **HotSDN 2012**
- **Control Plane**
  - On the Co-Existence of Distributed and Centralized Routing Control-Planes, **INFOCOM 2015**
  - CoVisor: A Compositional Hypervisor for Software-Defined Networks, **NSDI 2015**
  - A Network State Management Service, **SIGCOMM 2014**
- **Data Plane**
  - The (Surprising) Computational Power of the SDN Data Plane, **INFOCOM 2015**
  - Compiling Packet Programs to Reconfigurable Switches, **NSDI 2015**
  - Reclaiming the Brain: Useful OpenFlow Functions in the Data Plane, **HotNets 2014**
- **Hybrid Networks**
  - Traffic Engineering in SDN/OSPF Hybrid Networks , **ICNP 2014**
  - Reaping the Benefits of Partial SDN Deployment in Enterprise Networks, **USENIX 2014**
  - HybNET: Network Manager for A Hybrid Network Infrastructure, **Middleware 2013**

State of the Art

- **Cloud Computing and Big Data**
  - Meridian: An SDN Platform for Cloud Network Services, **IEEE Communications Magazine 2013**
  - Programming Your Network at Run-time for Big Data Applications, **HotSDN 2012**
  - Dynamic Graph Query Primitives for SDN-based Cloud Network Management, **HotSDN 2012**
- **Monitoring and Measurement**
  - Cracking Network Monitoring in DCNs with SDN, **INFOCOM 2015**
  - DREAM: Dynamic Resource Allocation for Software-defined Measurement, **SIGCOMM 2014**
  - Software Defined Traffic Measurement with OpenSketch, **NSDI 2013**
- **Network Security**
  - A Survey of Securing Networks Using Software Defined Networking, **Trans. on Reliability 2015**
  - FlowGuard: Building Robust Firewalls for Software-defined Networks , **HotSDN 2014**
  - FRESCO: Modular Compostable Security Services for Software-Defined Networks, **NDSS 2013**
- **SDN in WAN**
  - SDX: A Software Defined Internet Exchange, **SIGCOMM 2014**
  - B4: Experience with a Globally-Deployed Software Defined WAN, **SIGCOMM 2013**
  - Virtualizing the Access Network via Open APIs, **CoNEXT 2013**

SDN Research Beginnings

➢ Review and Survey

- Software-Defined Networking: A Comprehensive Survey, **Proceedings of IEEE 2015**
- The Road to SDN: An Intellectual History of Programmable Networks, **ACM Queue 2014**
- Abstractions for Software-Defined Networks, **Communications of the ACM 2014**
- A Survey of Software-Defined Networking: Past, Present, and Future of Programmable Networks, **IEEE Communications Surveys & Tutorials 2014**

➢ Famous Researchers

Nick McKeown
Stanford Univ.

Martin Casado
Vmware

Scott Shenker
U C Berkeley

Nick Feamster
Princeton Univ.

Jennifer Rexford
Princeton Univ.

Li Erran Li
Columbia Univ.

➢ Organization and Conference

OPEN NETWORKING FOUNDATION

OpenFlow

https://www.opennetworking.org/

ONS Open Networking Summit

SOSR: (from 2015)
ACM SIGCOMM Symposium on SDN Research

HotSDN: (2012~2014)
ACM SIGCOMM Workshop on Hot Topics in SDN

2 Our Work on SDN

A. The Architecture of SDN

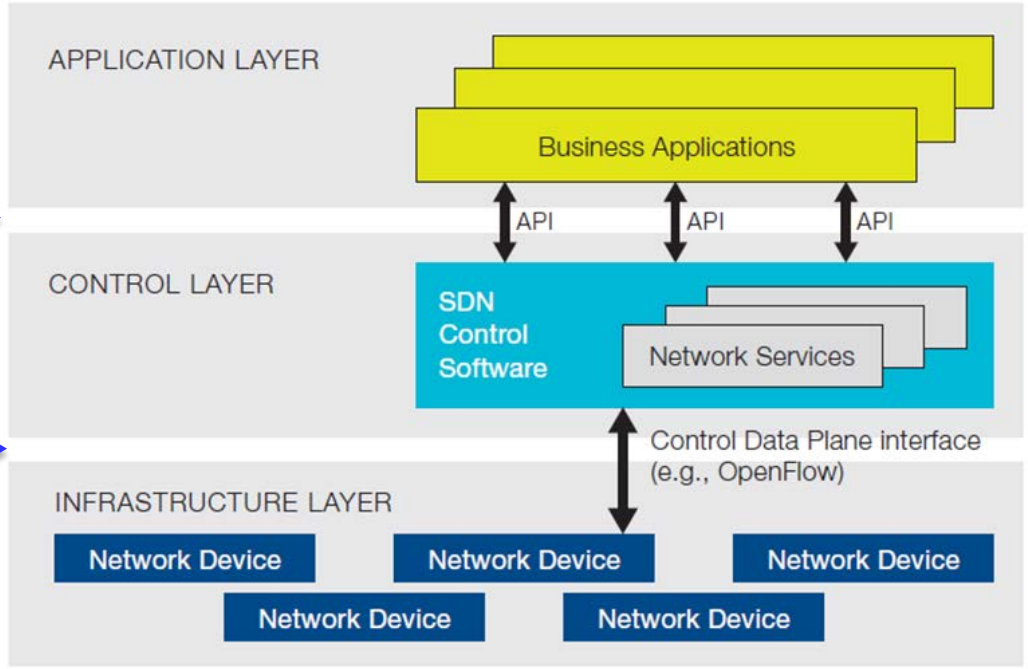
B. Datacenter with SDN

C. ACL App with SDN

The Architecture of SDN

North Interface →

South Interface →



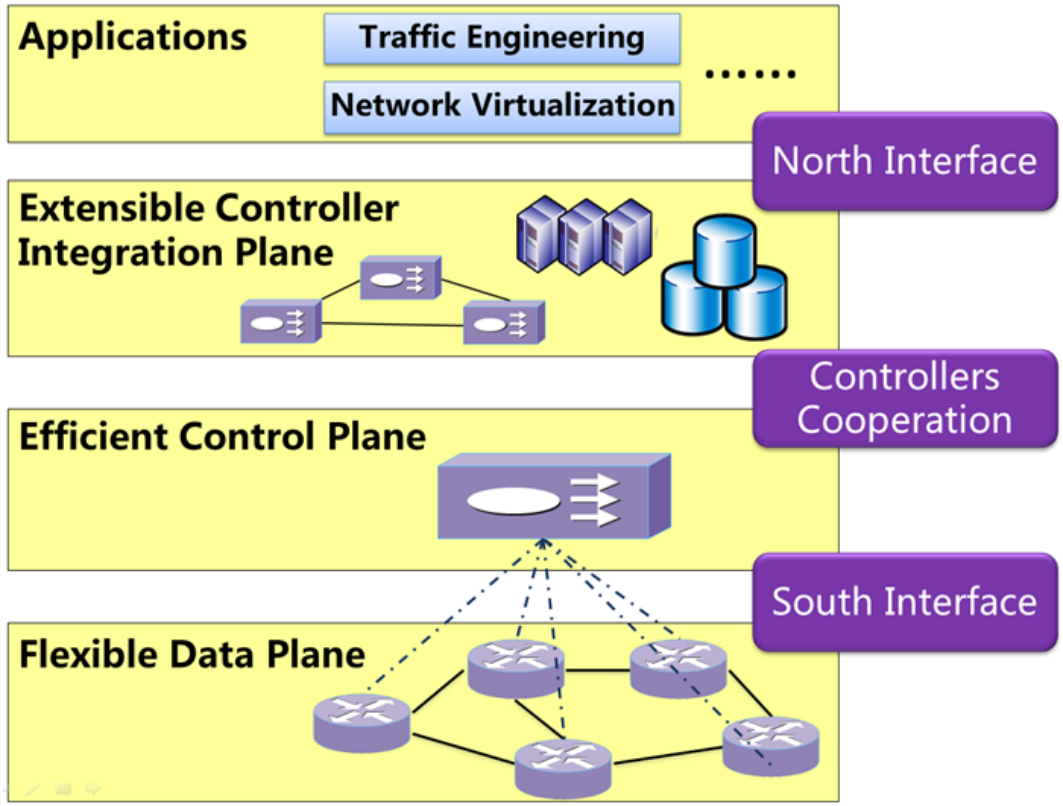
Drawbacks:

- The description of south interface is limited.
- The programmability of north interface is weak.
- The control layer is becoming more complex.

Four Layers Architecture

We propose:

Four Layers



Characteristics

- More flexible south interface
- Controller integration layer
- Public and programmability north interface

Flexible Data Plane

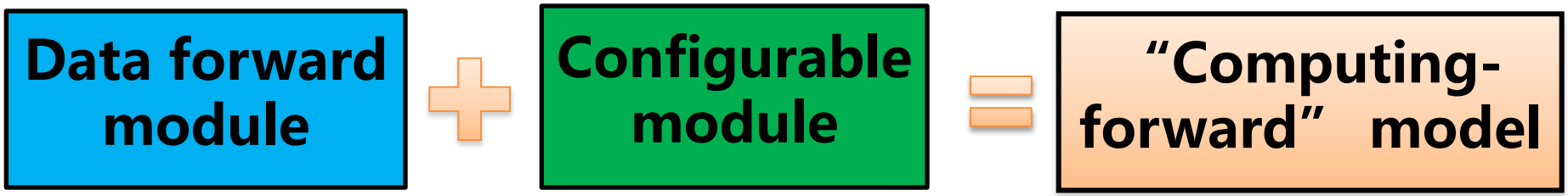
- **Problem :**

  Existing function of data plane is "matching-forward".

  It is difficult to realize complex network function.

- **Solution :**

  Combine simple configurable module and data forward module to realize "computing-forward" function model.



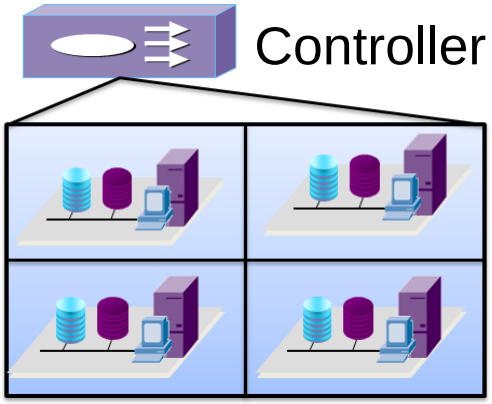
Efficient Control Plane

- **Problem :**

  It is difficult and time consuming to solve optimization problem with information of the whole network topology.

- **Solution :**

  Design information filtering algorithms to implement global towards optimization.



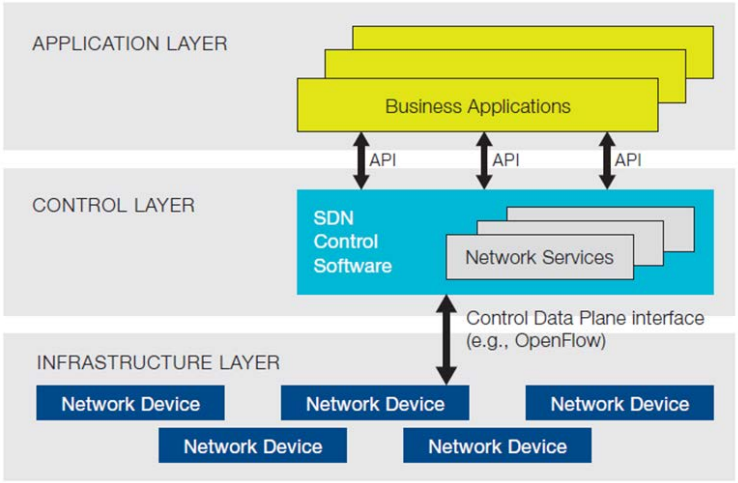
Network information collection

Information selection and filtering

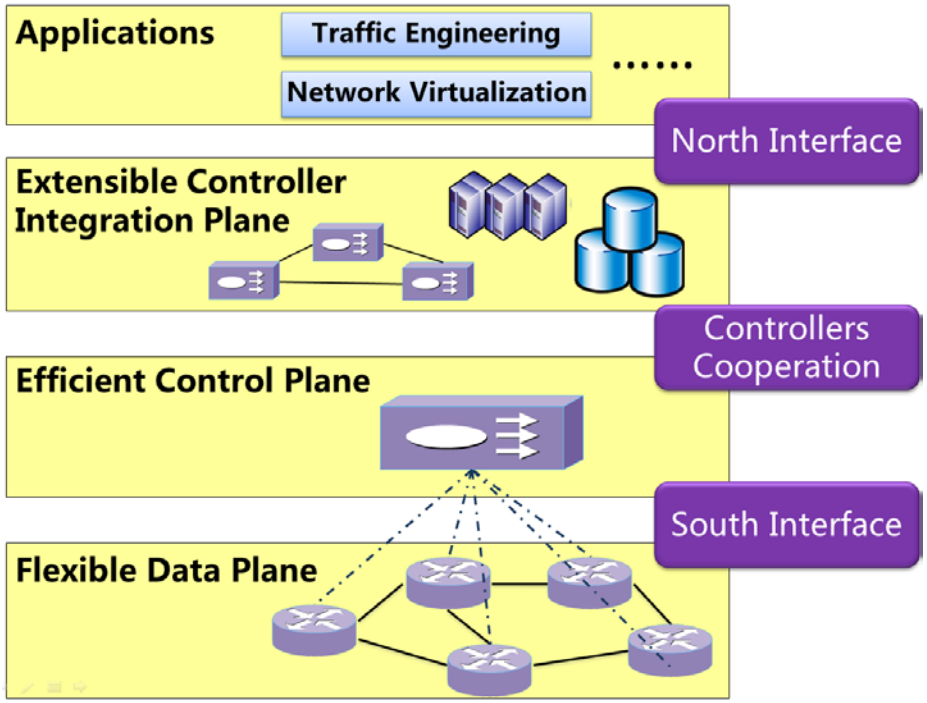
Global optimization model

Controller Integration Plane

A new plane for multiple controllers management, heterogeneity shielding, public north interface, and programmability .



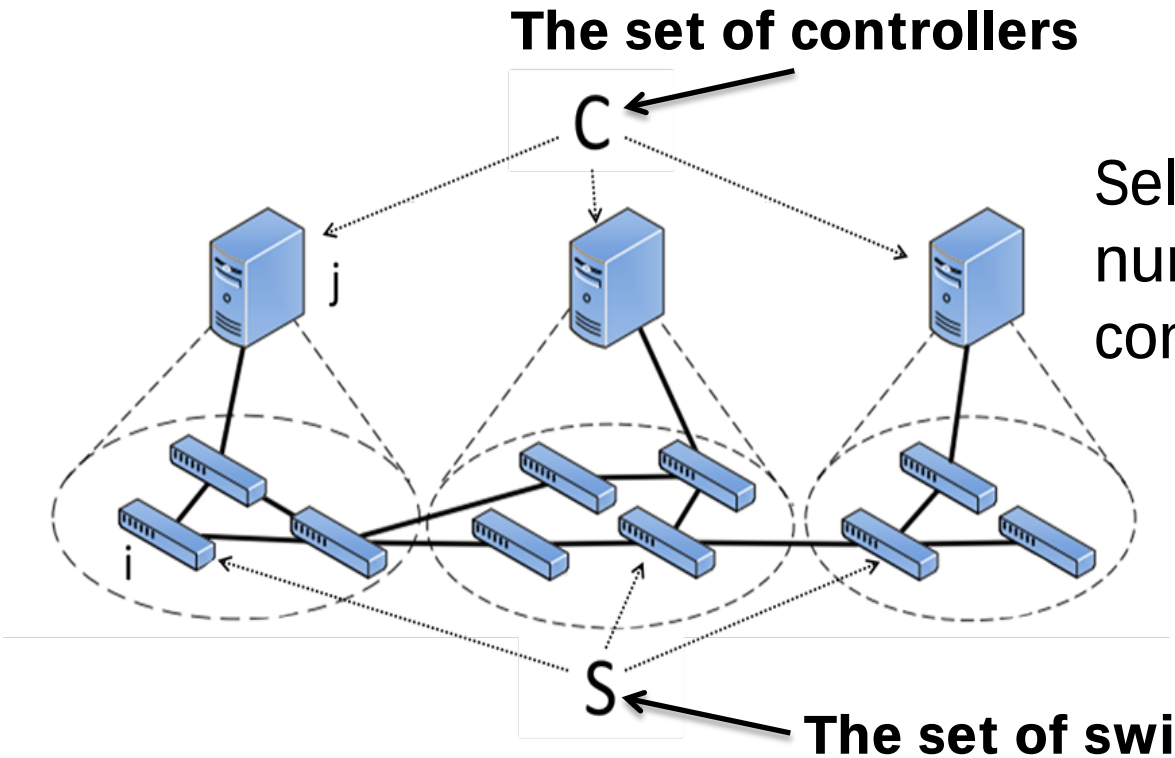
V.S.



Controller Integration Plane

Multiple Controller Management :

- **The placement of controllers**

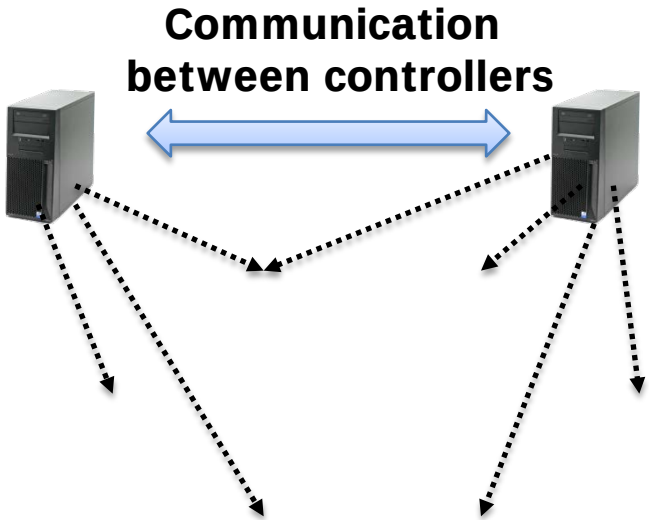


Selecting appropriate number of controllers and computing their positions.

Controller Integration Plane

Multiple Controller Management :

- **The placement of controllers**
- **The consistency of flow table updating**



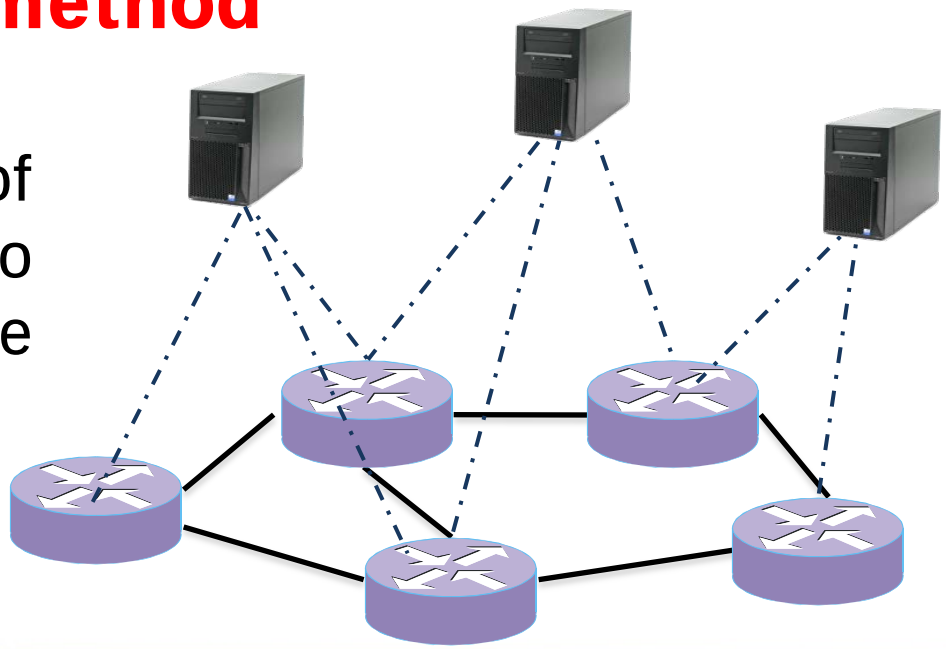
Propose the solution of communication between controllers to maintain the consistency of flow table updating.

Controller Integration Plane

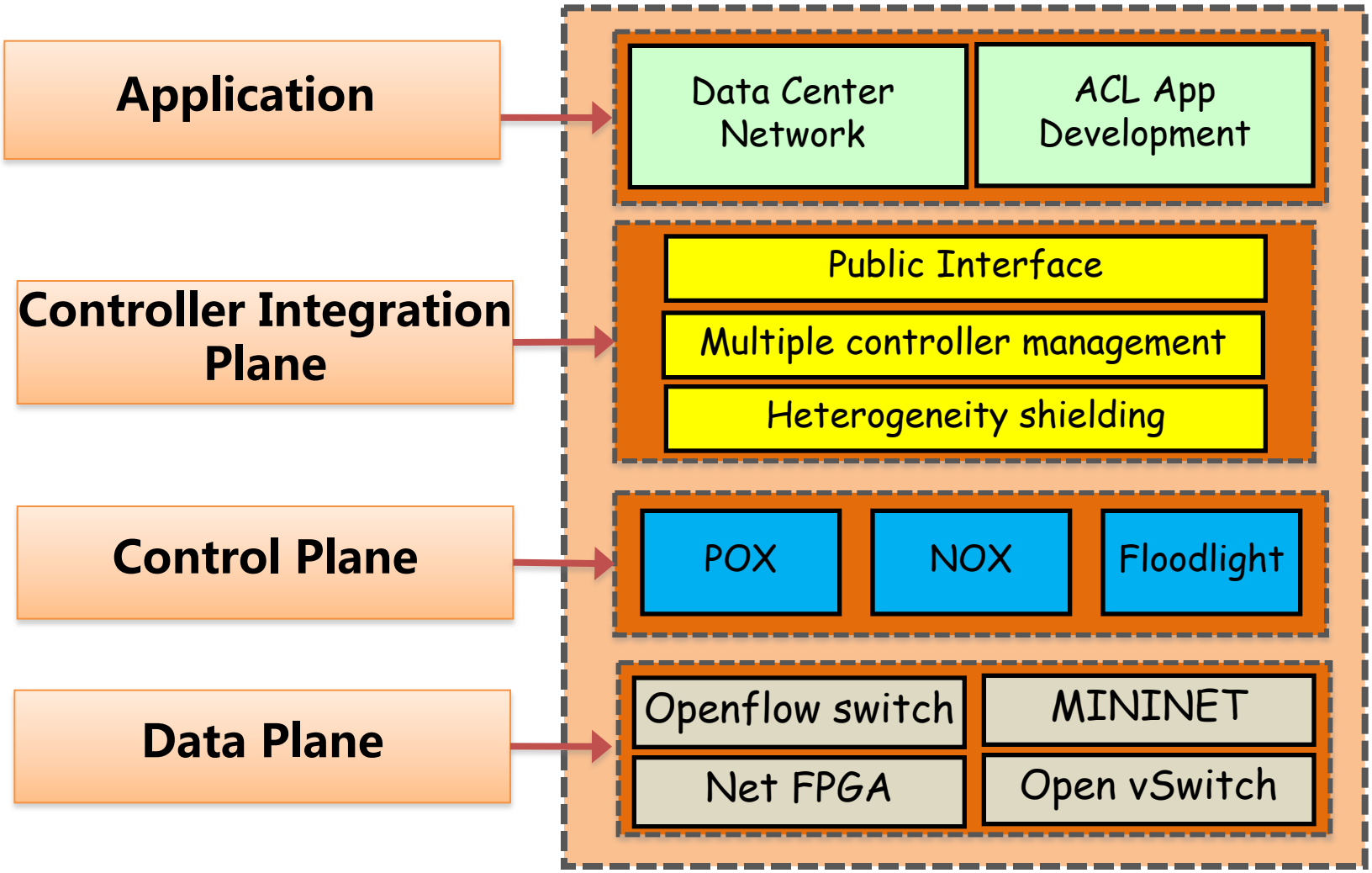
Multiple Controller Management :

- **The placement of controllers**
- **The consistency of flow table updating**
- **Dynamic migration method**

Design an effective method of dynamic switch migration to achieve the load balance between multiple controllers.



Our SDN Testbed for 4 layers

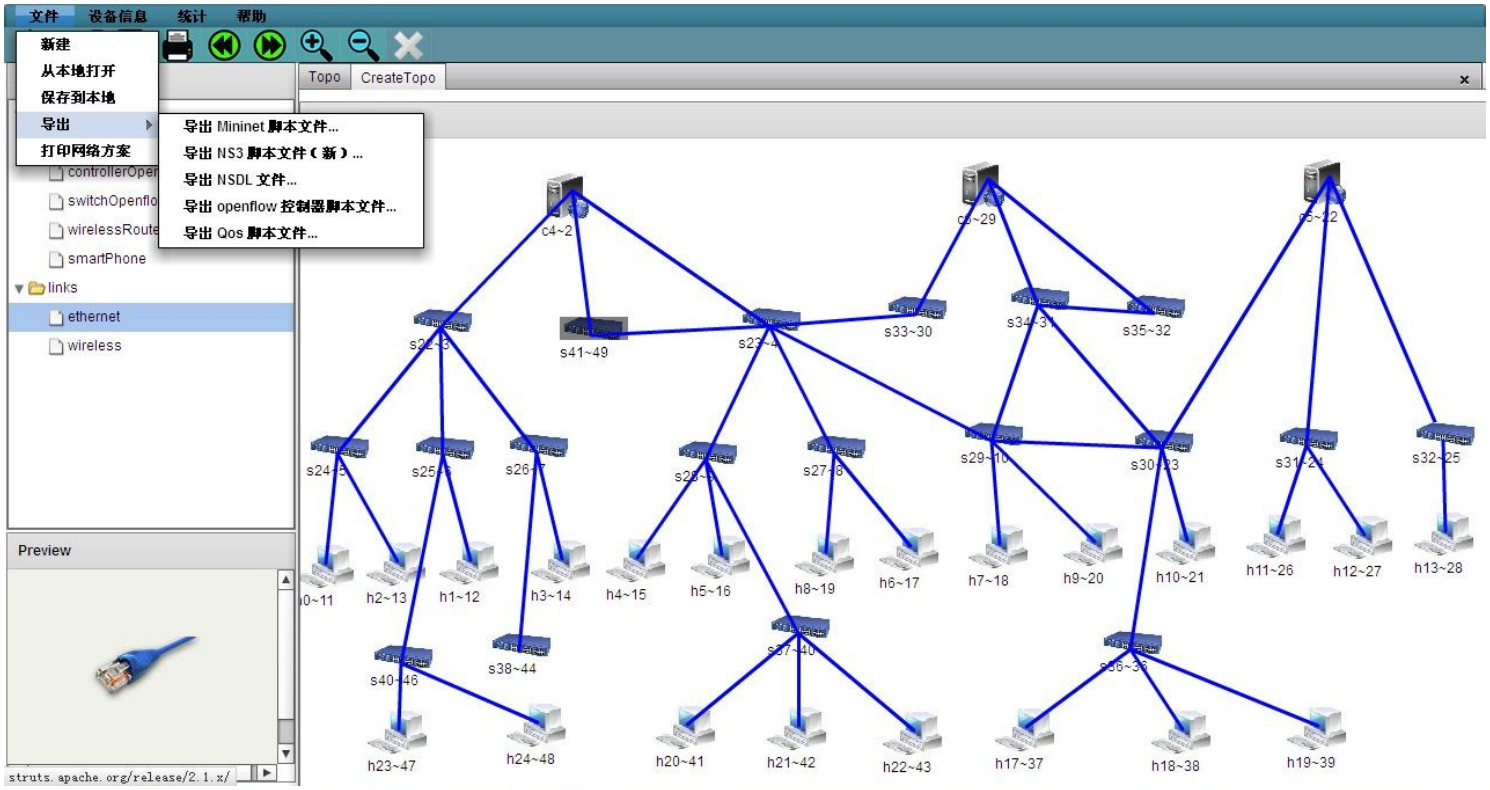


Our SDN Testbed for 4 layers

The characteristics of testbed : 3 Easy to

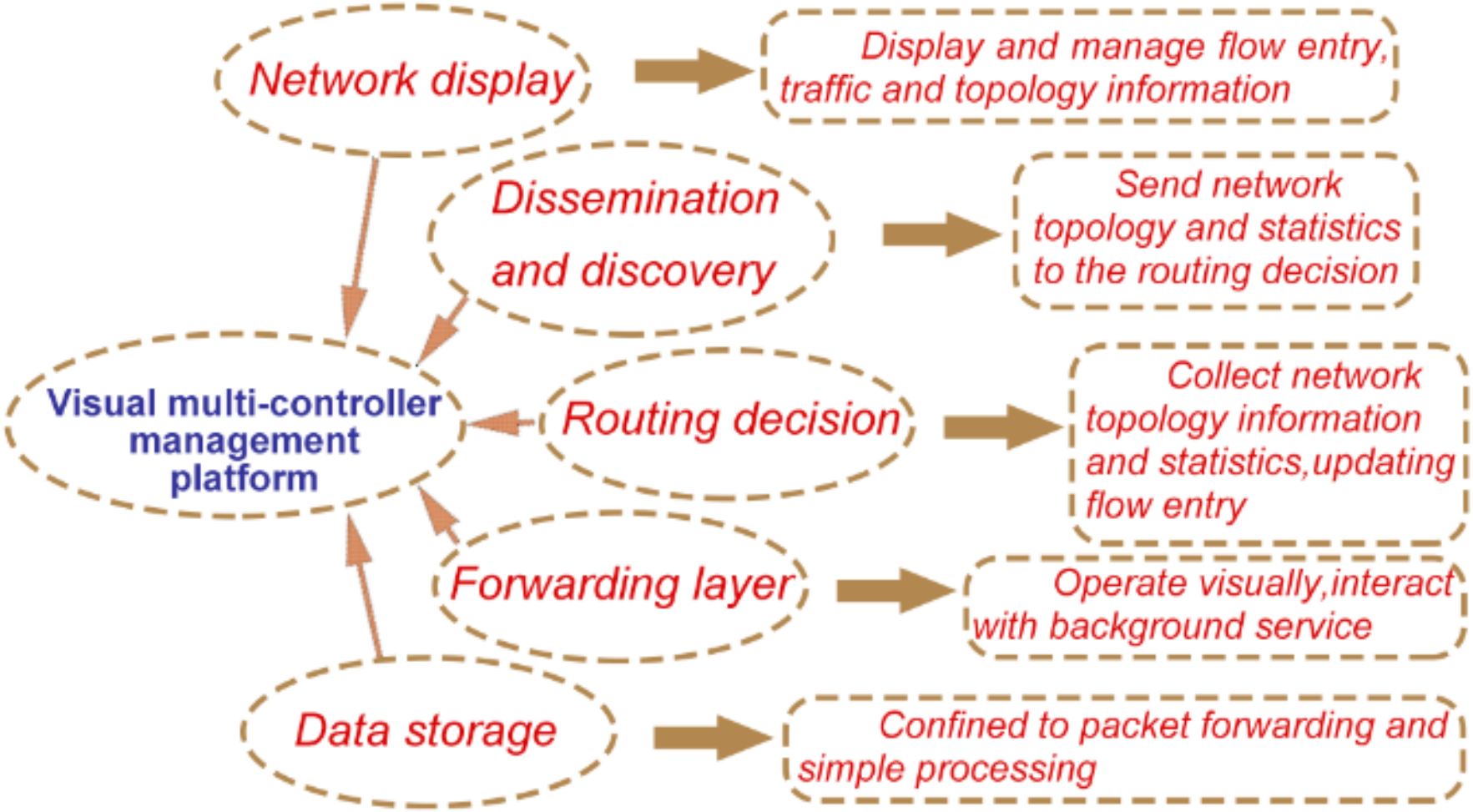
- implement the simulation or real experiments.
- develop innovative applications.
- design high level programming language.

Visualization experimental platform



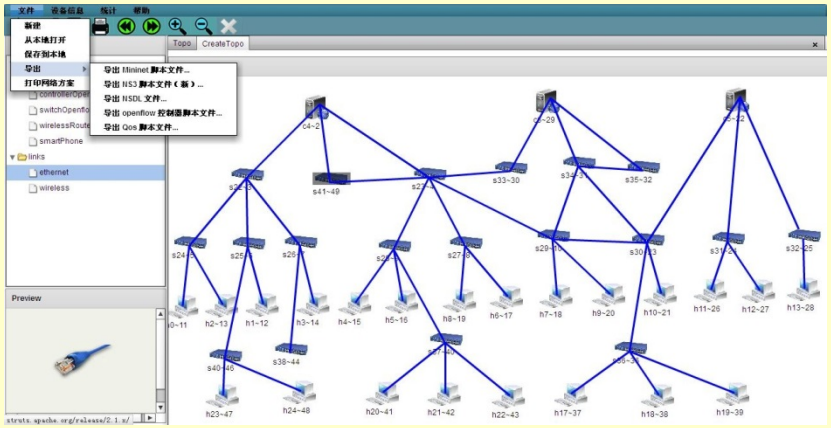
Our SDN Testbed for 4 layers

Modules of Platform :

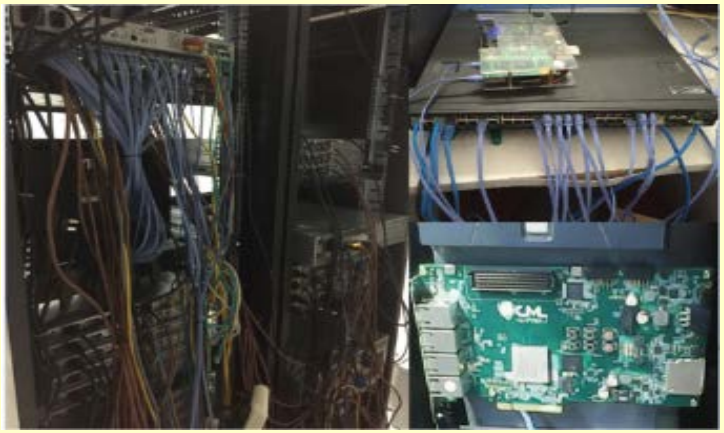


Our SDN Testbed for 4 layers

A Visual Multi-Controller Management Platform For SDN



User Interface



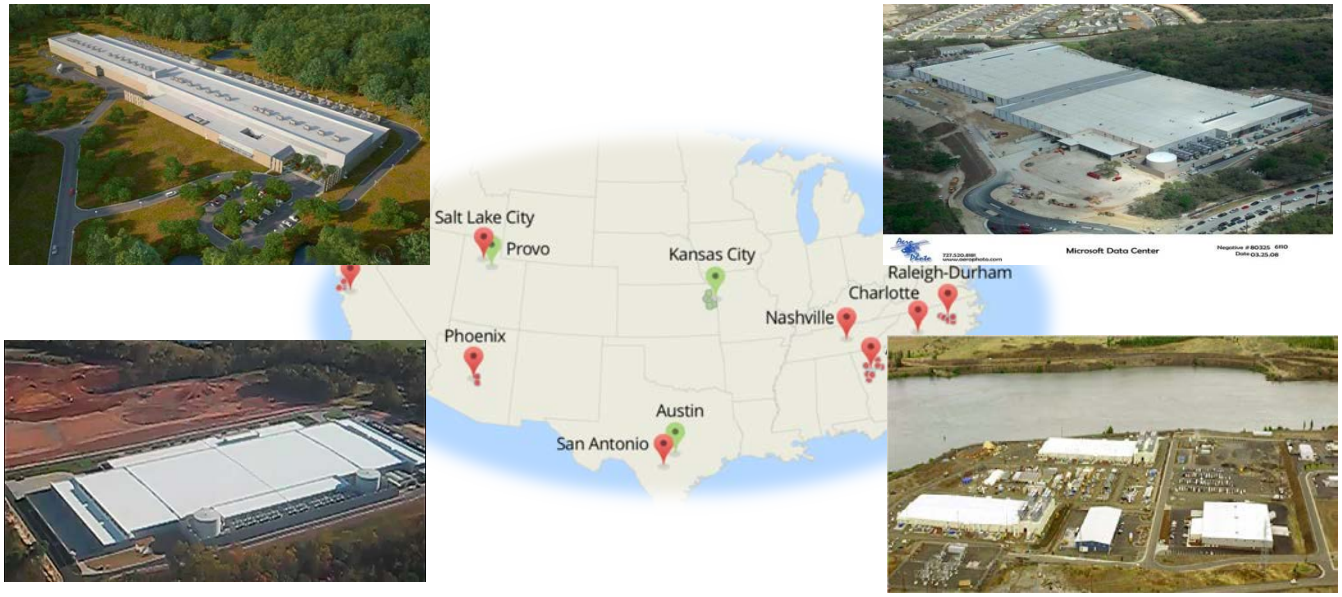
Infrastructure

- Haisheng Yu, Keqiu Li，Heng Qi, Wenxin Li and Xiaoyi Tao，"Zebra: An East-West Control Framework For SDN Controllers", **The 44th Annual Conference on Parallel Processing (ICPP) 2015**.
- Haisheng Yu, Heng Qi, Yinping Li, Junxiao Wang, Sheng Chen, Keqiu Li, "Slope: A Visual Multi-Controller Management Platform For SDN", **Open Networking Summit & ACM SIGCOMM Symposium on SDN Research (ONS & SOSR) 2015**.

Data Center Network with SDN

Background :

- Large-scale internet applications (e.g. social network) usually deploy geographically distributed datacenters.
- This leads to **request allocation problem** in which low latency and load balance should be considered.



SDN-based Request Allocation

The benefit of SDN :

1、Collecting global information of network

2、Allocating users' request by controller

3、Request allocation based on global information

Problems should be addressed:

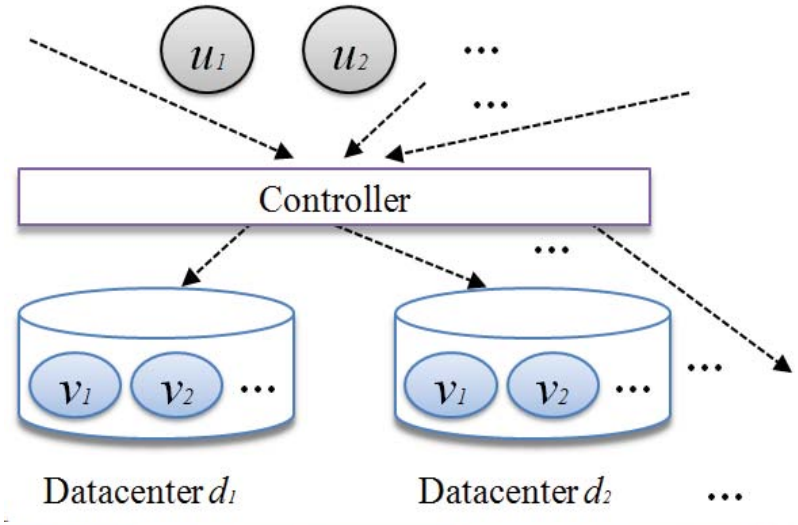
How to build an effective and efficient model to find a optimization solution for request allocation based on global information of network.

Joint optimization of bandwidth efficiency and delay

SDN-based Request Allocation

Joint optimization of bandwidth efficiency and delay

- We propose a joint optimization model of bandwidth efficiency and user delay for allocating user request among multiple data centers. We further propose efficient request allocation algorithm based on the Logarithmic Smoothing technique



$$\max_{x(j,k,i)} \quad \prod_j p(j) + \prod_k \frac{1}{t(k)}$$

$$\text{s.t.} \quad \forall j, \sum_{k,i} r(k,i)b(i)x(j,k,i) \le c(j),$$

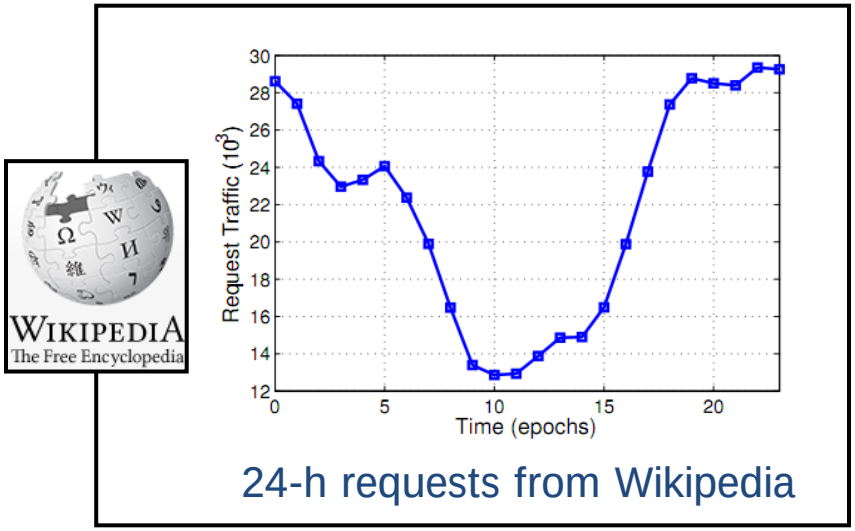
$$\forall k, \forall i, \sum_j x(j,k,i) = 1,$$

$$\forall j, \forall k, \forall i, x(j,k,i) \in \{0,1\}.$$

SDN-based Request Allocation

Simulation with real-world workload traces :

- 5 datacenters
- 100 application instances
- 500 users
- Request from Wikipedia



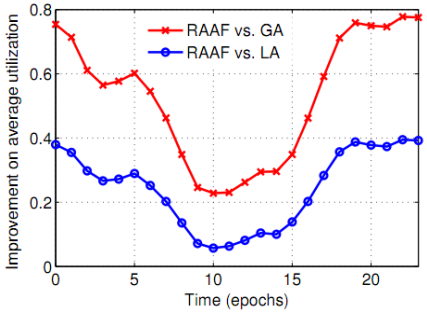
24-h requests from Wikipedia

Performance evaluation :

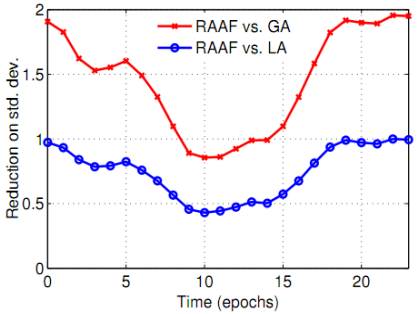
- Compare with locality algorithm (LA) and greed algorithm (GA)
- Performance metrics: bandwidth utilization, user delay and ability of request processing.

SDN-based Request Allocation

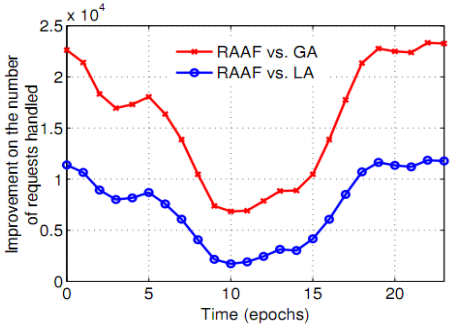
Experiment results:



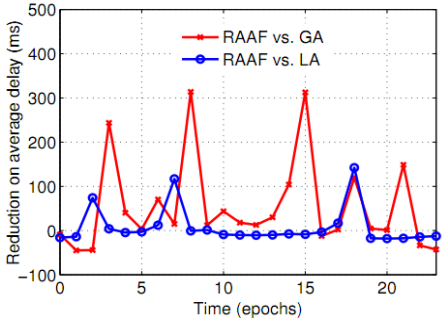
Average of improvement on bandwidth utilization



Standard deviation of the bandwidth utilization



The number of requests successfully handled



Average of reduction on user delay

- Wenxin Li, Heng Qi, Keqiu Li, Ivan Stojmenovic and Julong Lan, "Joint Optimization of Bandwidth for Provider and Delay for User in Software Defined Data Centers", **IEEE Transactions on Cloud Computing (TCC)**.
- Wenxin Li, Deke Guo, Keqiu Li, Heng Qi and Jianhui Zhang, "iDaaS: Inter-datacenter Network as a Service", **IEEE Transactions on Parallel and Distributed Systems (TPDS)**
- Jianhui Zhang, Keqiu Li, Deke Guo, Heng Qi and Wenxin Li, "ATFQ: A Fair and Efficient Packet Scheduli ng Method in Multi-resource Environments", **IEEE Transaction on Network and Service Management (TNSM)**

ACL App with SDN

Background：

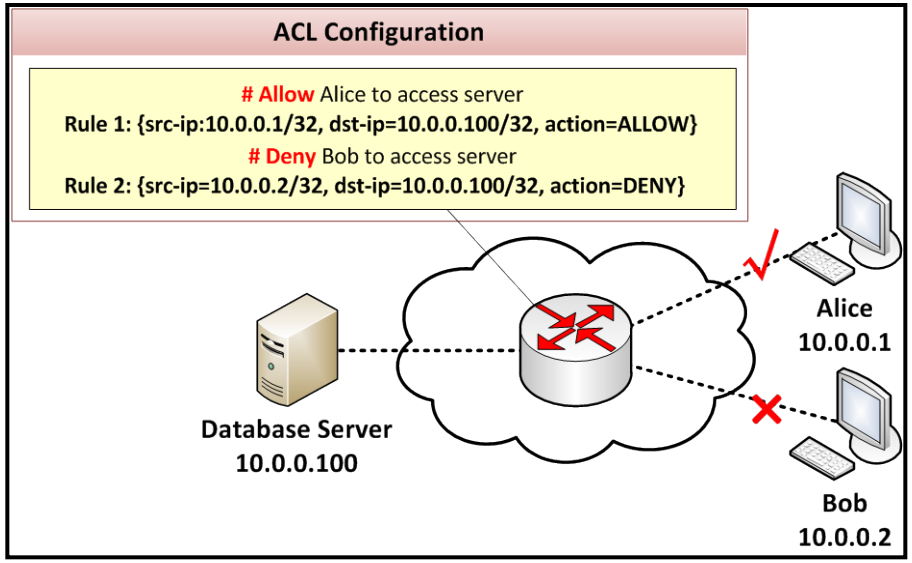
- Access Control List (ACL) is a network security enhancement.
- In traditional networks, ACL is often placed in network device.

•Network devices should have appropriate hardware and processing capabilities to enforce ACL.

•It is too complicated to design and configure ACL in distributed network devices.

We can use global network view provided by SDN for ACL App

SDN
Software Defined Networking



ACL App with SDN

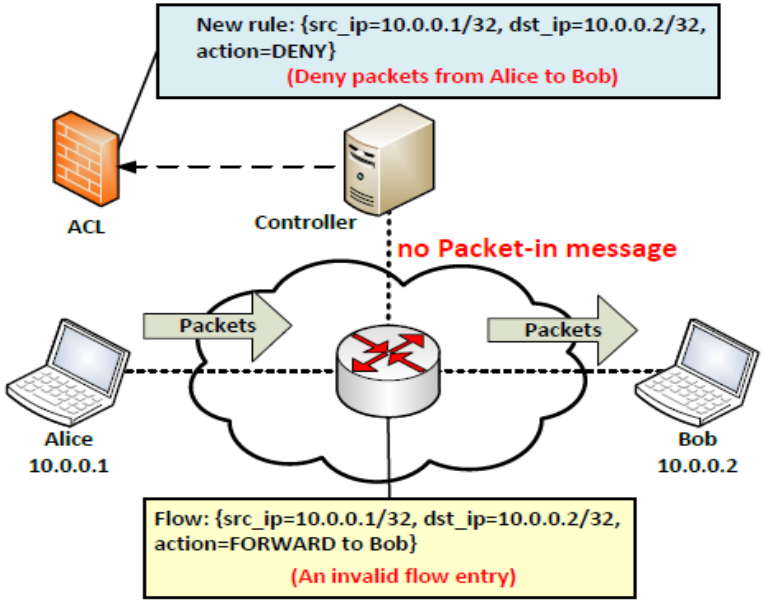
Existing ACL App with SDN :

- An Openflow-based Prototype of SDN-Oriented Stateful Hardware Firewalls (**ICNP 2014**)
- Floodlight Firewall Application (**famous open controller**)

https://floodlight.atlassian.net/wiki/display/floodlightcontroller/Firewall

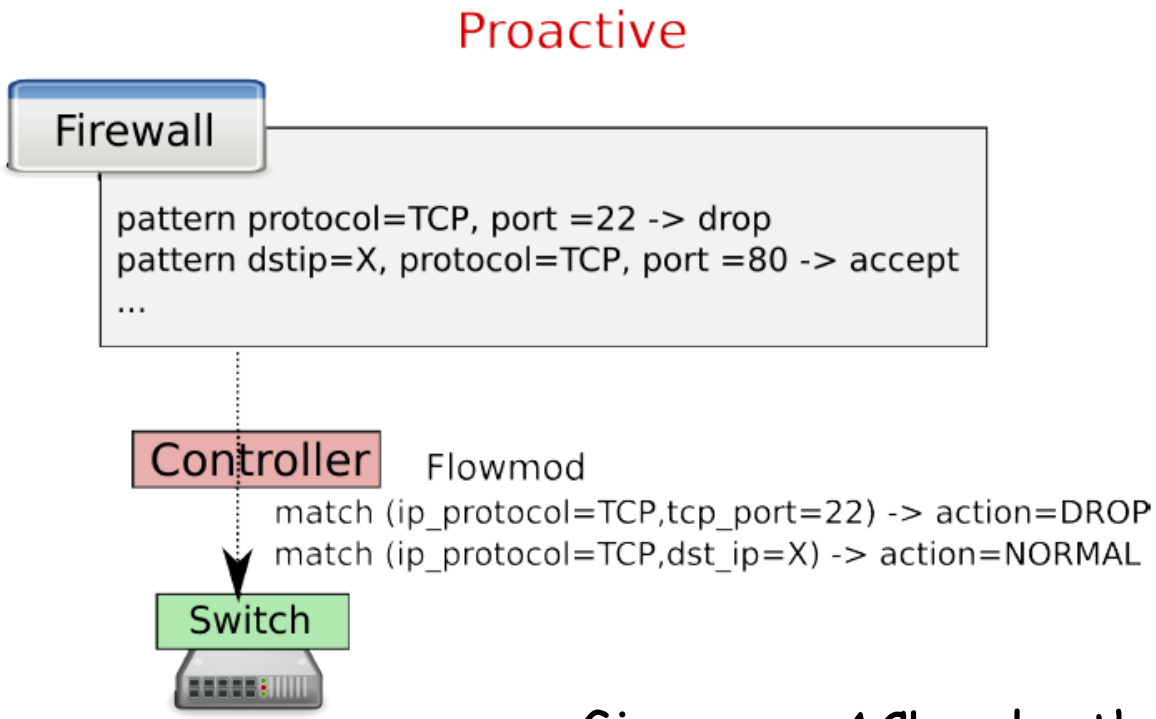
Reactive way:

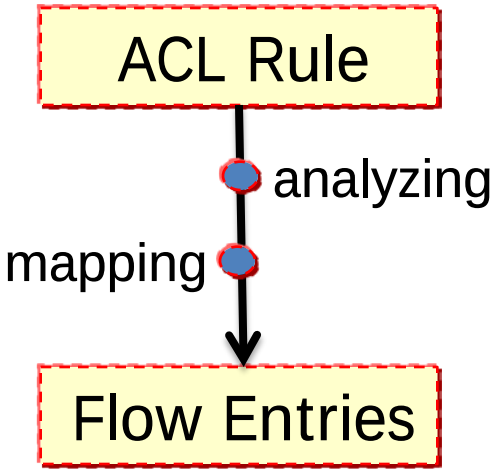
When one old flow entry remains in switch, there is no packet-in message. So the new ACL rule can not work until the old flow entry becomes invalid.



ACL App with SDN

We propose to realize ACL in proactive way:

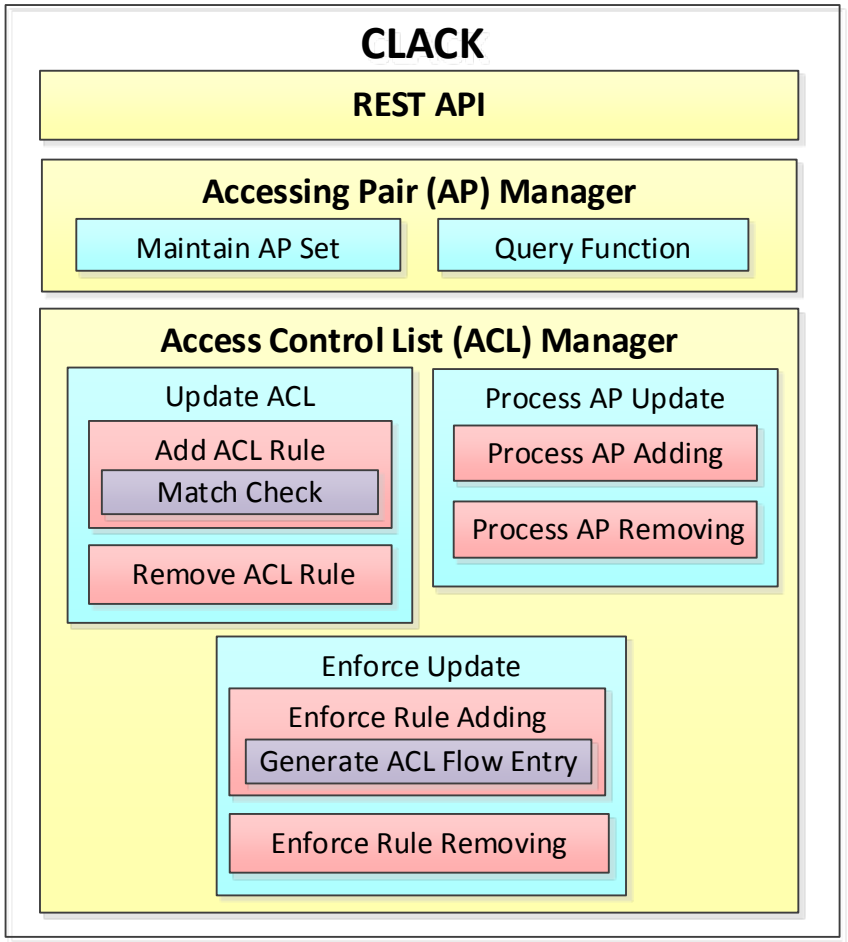




Given one ACL rule, the App can map this rule into flow entries. Then, these flow entries can be installed in switches directly.

ACL App with SDN

CLACK: Centralized Access Control List in SDN



Two versions :

- CLACK for Floodlight (Single)

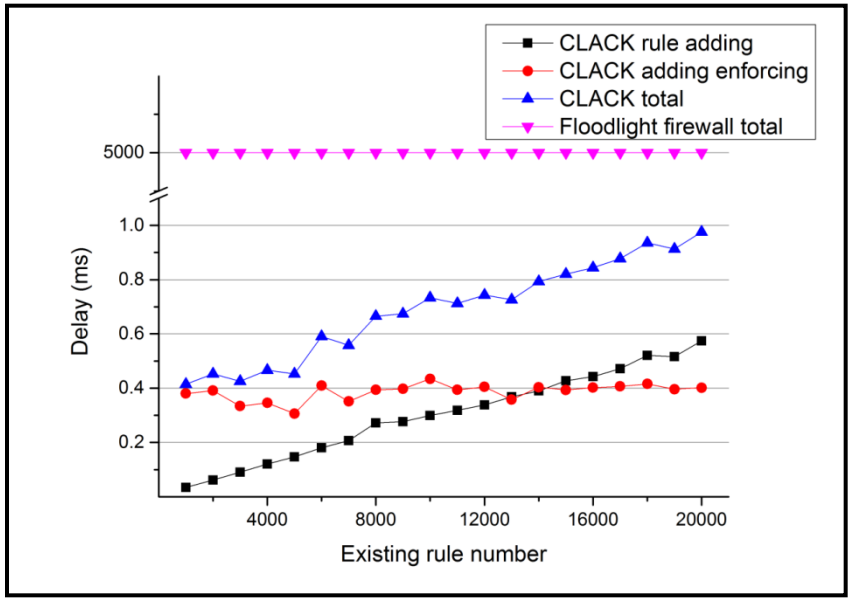
Project Floodlight

- CLACK for ONOS (Distribute)

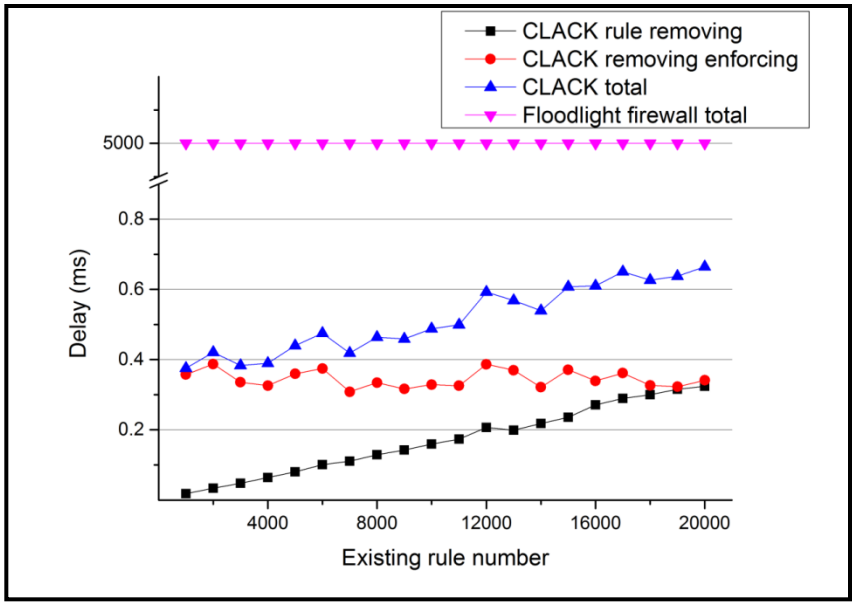
ONOS
Open Network Operating System

ACL App with SDN

Performance evaluation: v.s Floodlight firewall App



Add a new ACL rule

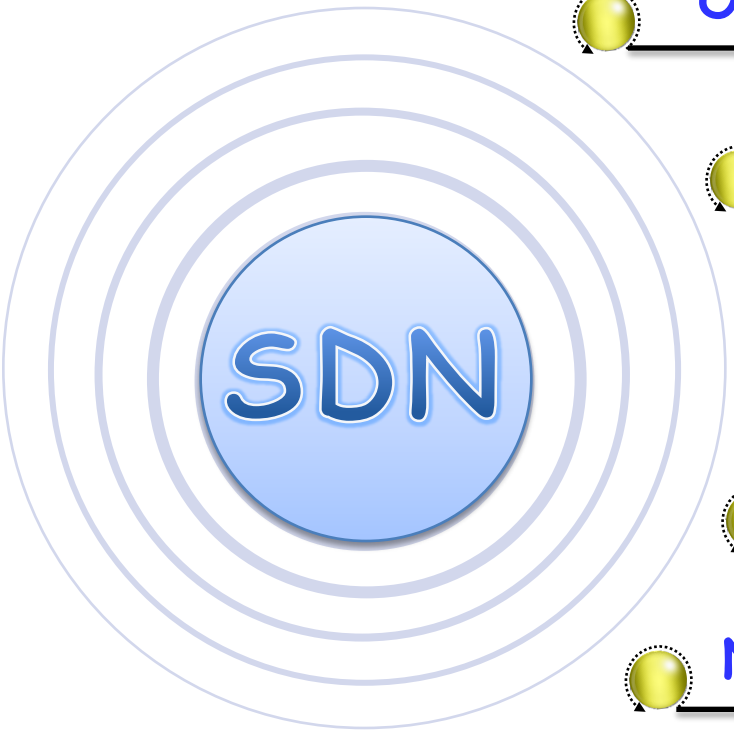


Remove an existing ACL rule

- CLACK has been integrated into Floodlight v1.1.
- CLACK has been accepted by ONOS community.

Conclusions: SDN Future

Future work :



- Openflow improvement.
- High level network programming
- Enhanced data plane
- Extensible control plane
- New needs & new applications

Thank you !