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# Advanced Networking and Future Internet

## V. Software-Defined Networking

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# Advanced Networking and Future Internet: Software-Defined Networking

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# 1. Introduction

## 1. Legacy Networking Technology Limitations

- Large set of various protocols, slow standardization
- Buggy equipment software
- Huge network operation costs
- Risk of inconsistent policies and configurations
- Scalability
- Vendor dependence and closed equipment

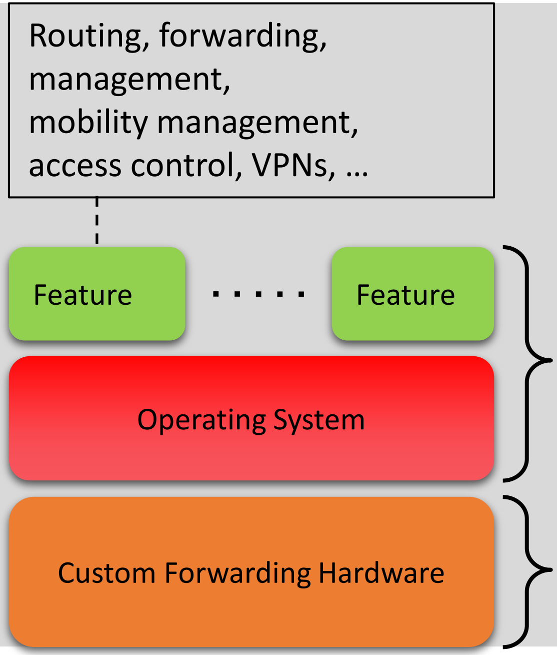
# 1. Introduction

# 2. Network Device Architecture

– extremely complex

– mainframe mentality

– very expensive

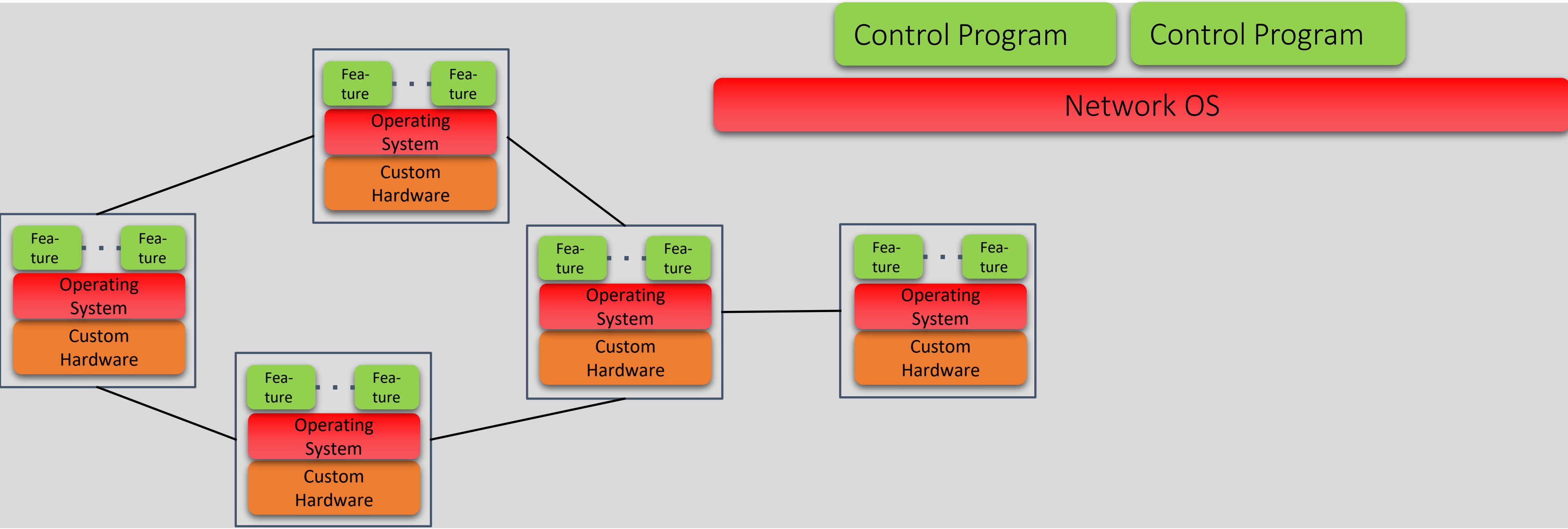


millions of lines of source code (based on > 8000 RFCs)

billions of power-hungry gates

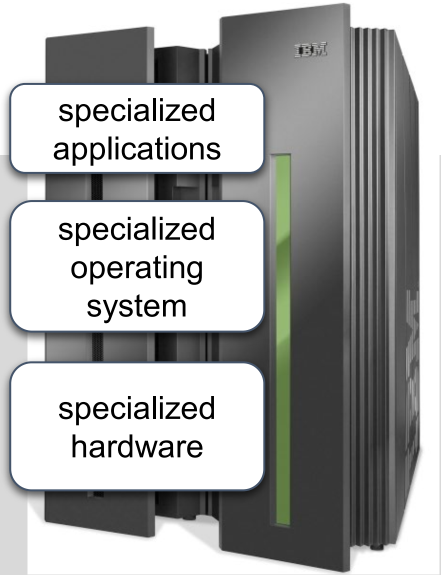
# 1. Introduction

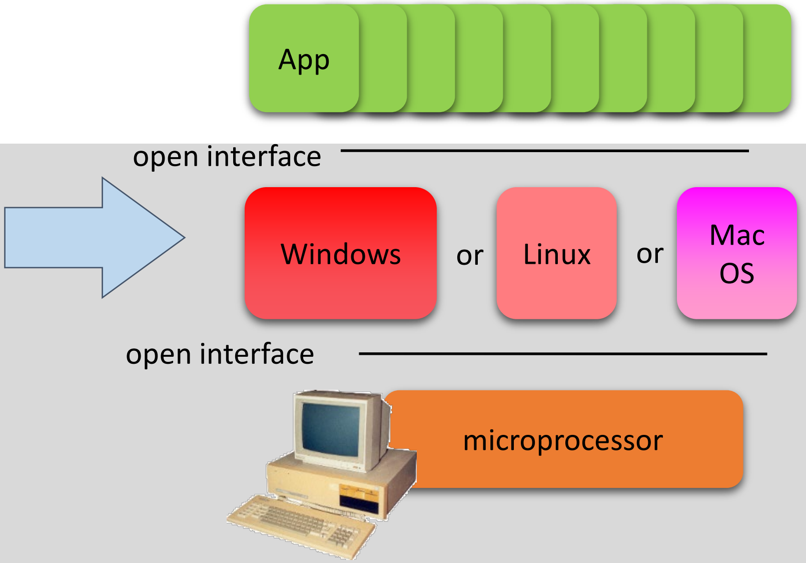
# 3. Restructuring Networks



# 1. Introduction

## 4. Mainframes



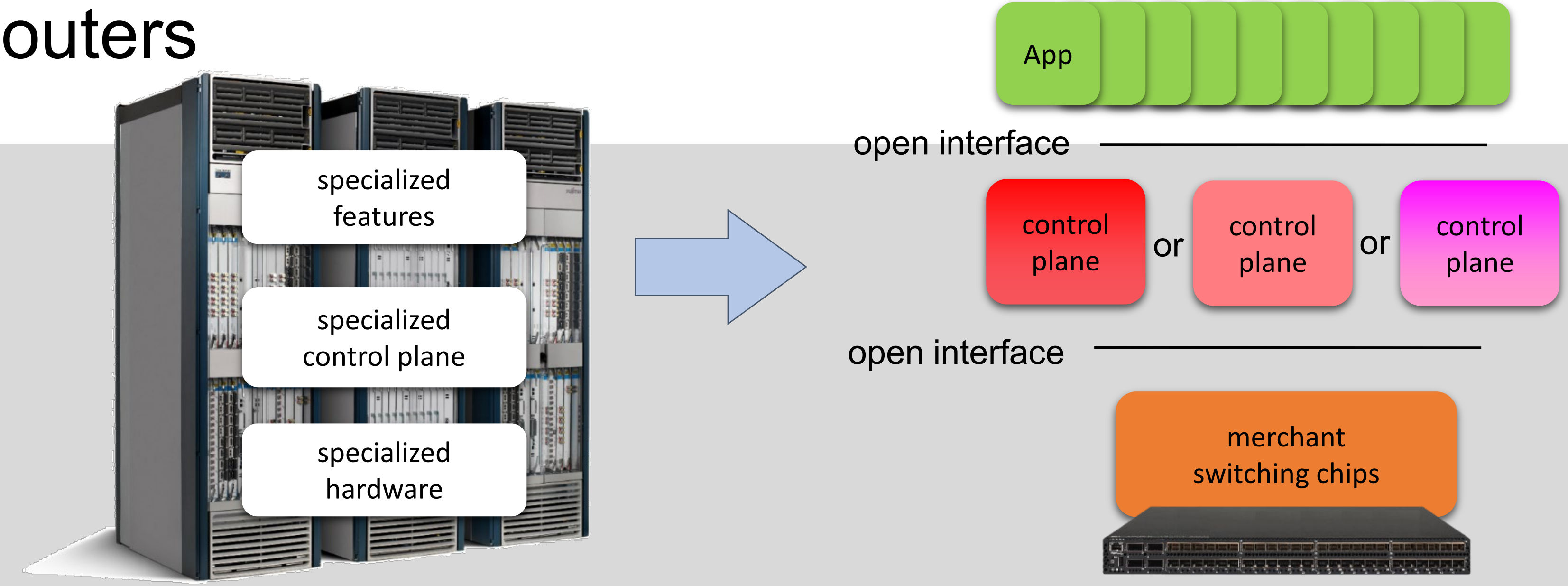


- vertically integrated
- closed, proprietary
- slow innovation
- small industry

- horizontal
- open interfaces
- rapid innovation
- huge industry

# 1. Introduction

## 5. Routers



specialized features

specialized control plane

specialized hardware

App

open interface

control plane or control plane or control plane

open interface

merchant switching chips

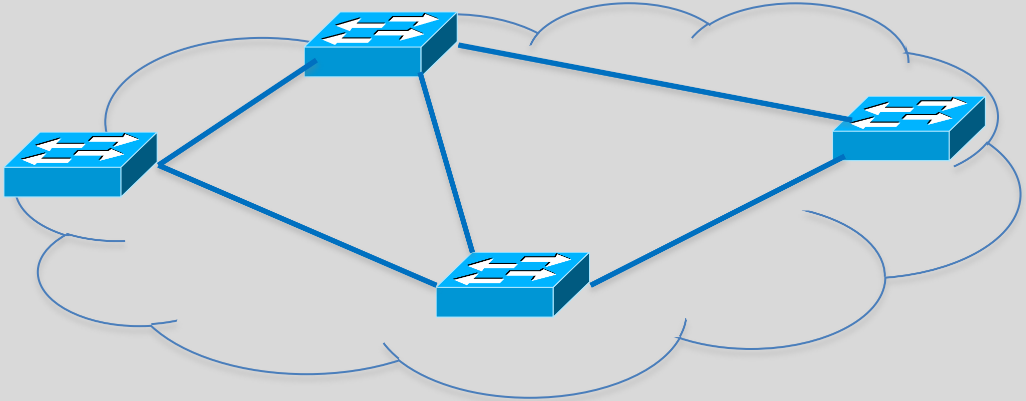
- vertically integrated
- closed, proprietary
- slow innovation

- horizontal
- open interfaces
- rapid innovation

# 1. Introduction

## 6.1 Traditional Computer Networks: Data Plane

data plane: packet handling

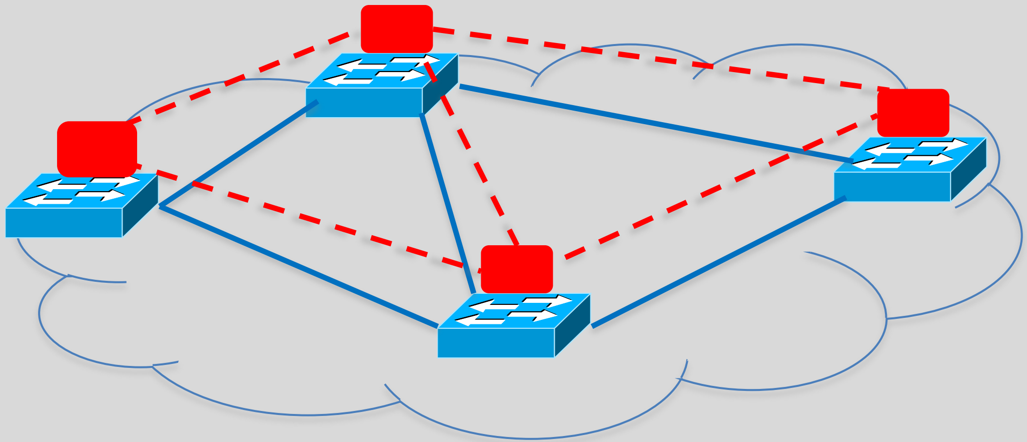


forward, filter, buffer, mark, rate-limit, measure packets

# 1. Introduction

## 6.2 Traditional Computer Networks: Control Plane

control plane: distributed algorithms

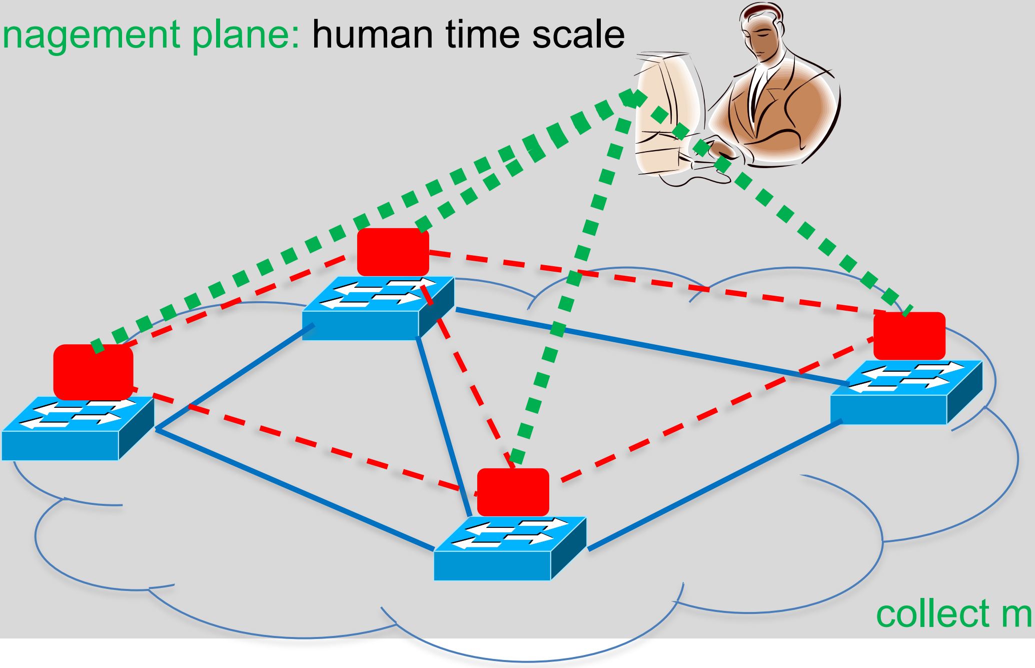


track topology changes, compute routes, install forwarding rules

# 1. Introduction

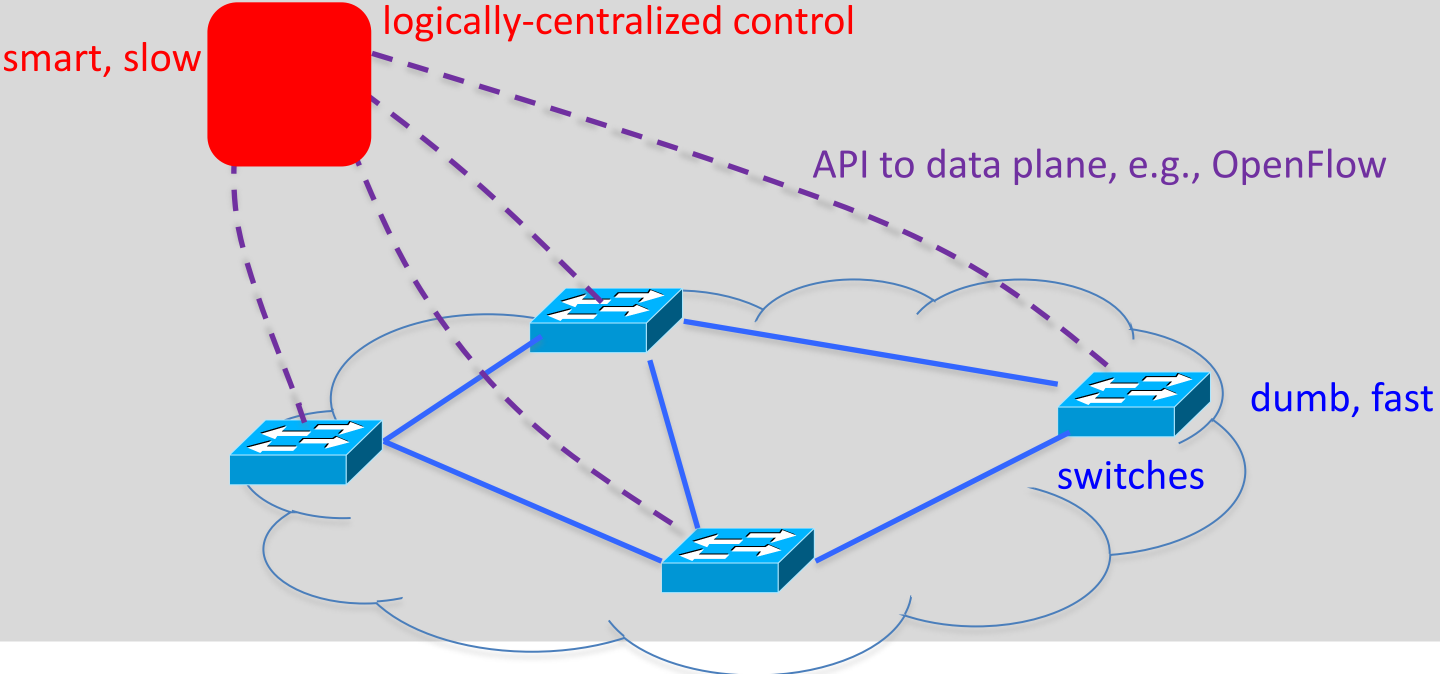
## 6.3 Traditional Computer Networks: Management Plane

management plane: human time scale



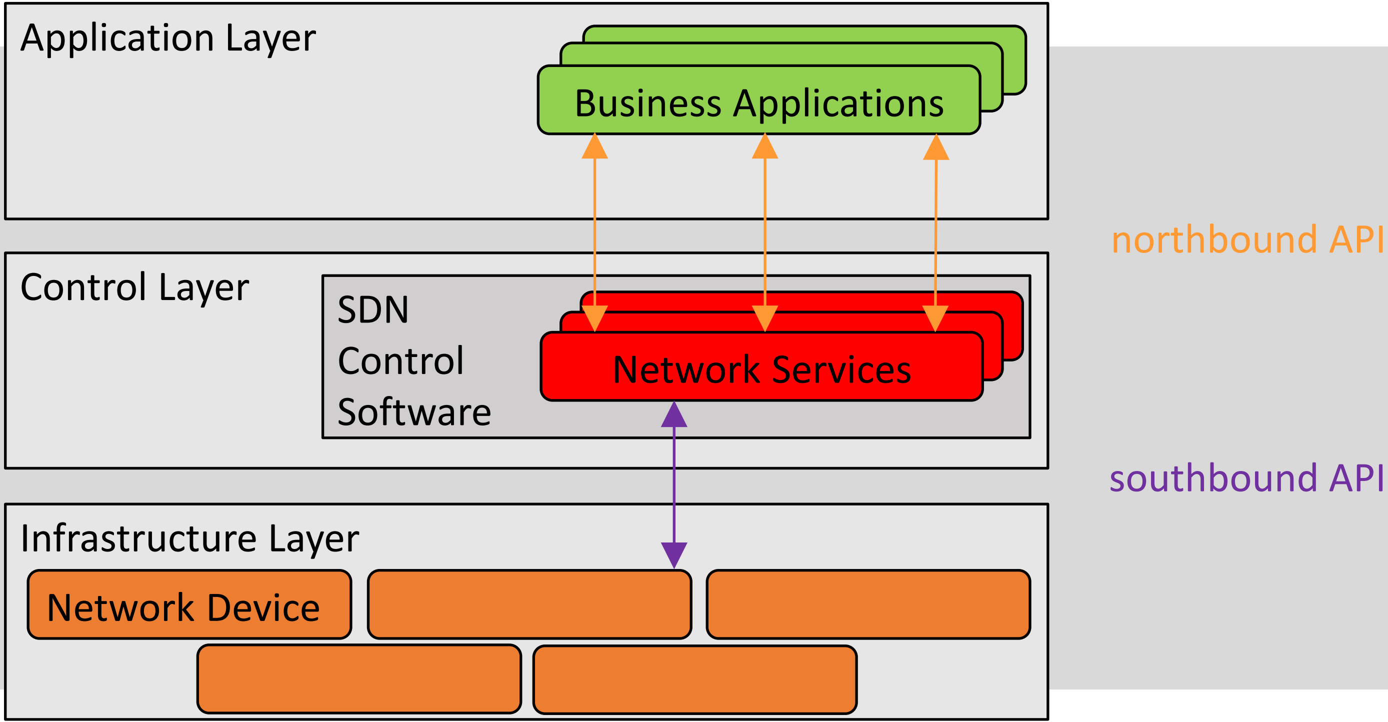
collect measurements and configure equipment

# 2. Software Defined Networking


logically-centralized control
smart, slow
API to data plane, e.g., OpenFlow
dumb, fast
switches

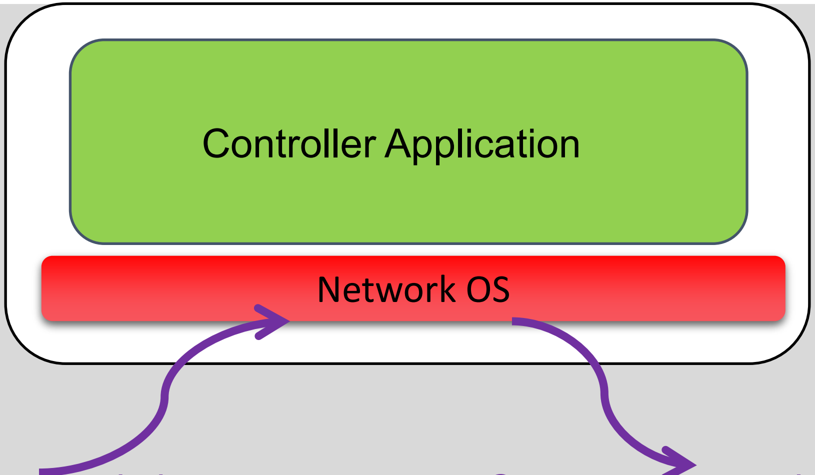
# 2. Software Defined Networking

## 1. Architecture



# 2. Software Defined Networking

## 2. Controller: Programmability



Events from switches

- topology changes
- traffic statistics
- arriving packets

Commands to switches

- (un)install rules
- query statistics
- send packets

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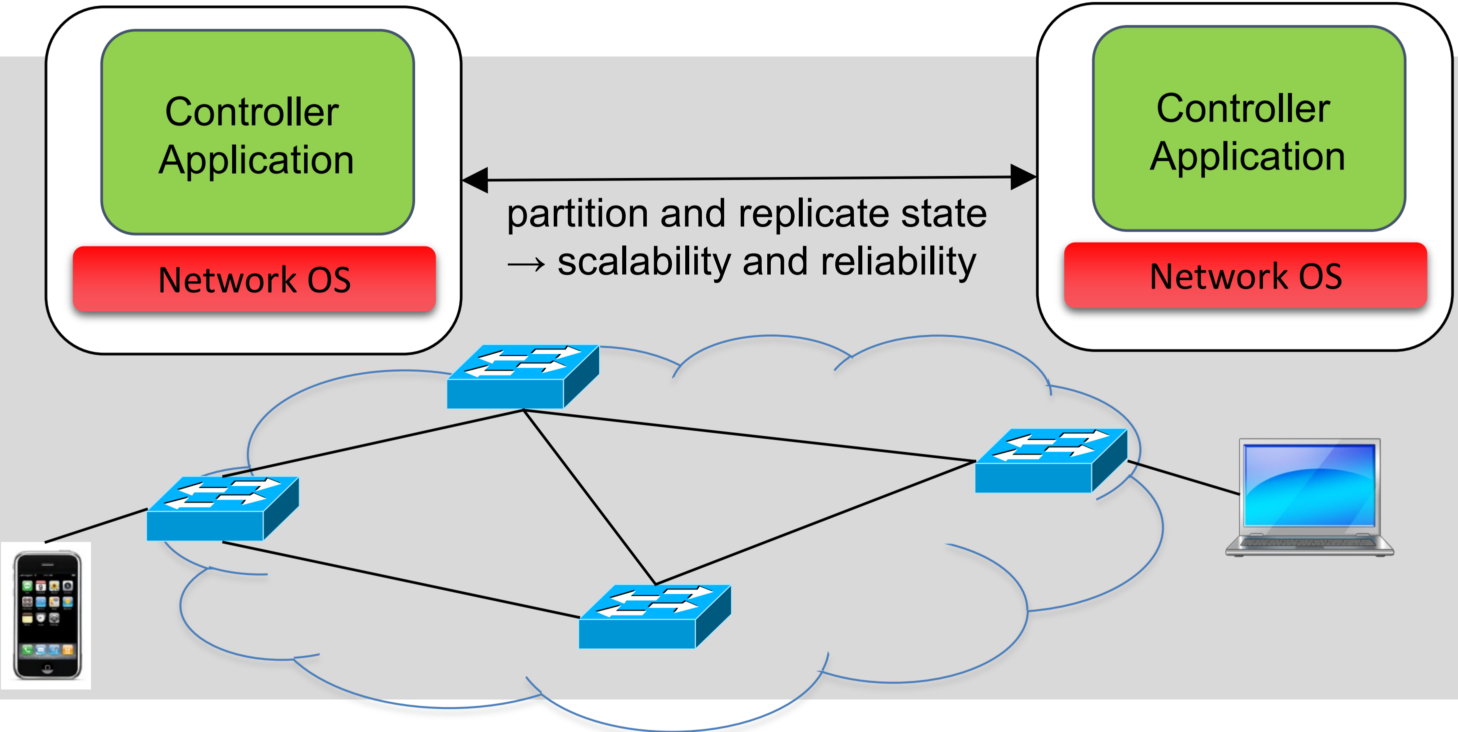
## 2. Software Defined Networking

## 3. Distributed Controller



partition and replicate state
→ scalability and reliability

# 2. Software Defined Networking

## 4. Data Plane: Simple Packet Handling Rules

- Pattern: match packet header bits
- Actions: drop, forward, modify, send to controller
- Priority: disambiguate overlapping patterns
- Counters: #bytes and #packets (received, transmitted, dropped, erroneous, …)

| MAC src | MAC dst | IP src | IP dst | TCP dst port | … | Action | Count |
|---|---|---|---|---|---|---|---|
| * | 10:20:… | * | * | * | * | Port1 | 250 |
| * | * | * | 5.6.7.8 | * | * | Port2 | 300 |
| * | * | * | * | 25 | * | Drop | 892 |
| * | * | * | 192.* | * | * | Local | 120 |
| * | * | * | * | * | * | Controller | 11 |

# 2. Software Defined Networking

## 5. Network Devices

**Router**

- Match:
  longest destination IP prefix
- Action: forward via a link

**Switch**

- Match:
  destination MAC address
- Action: forward or flood

**Firewall**

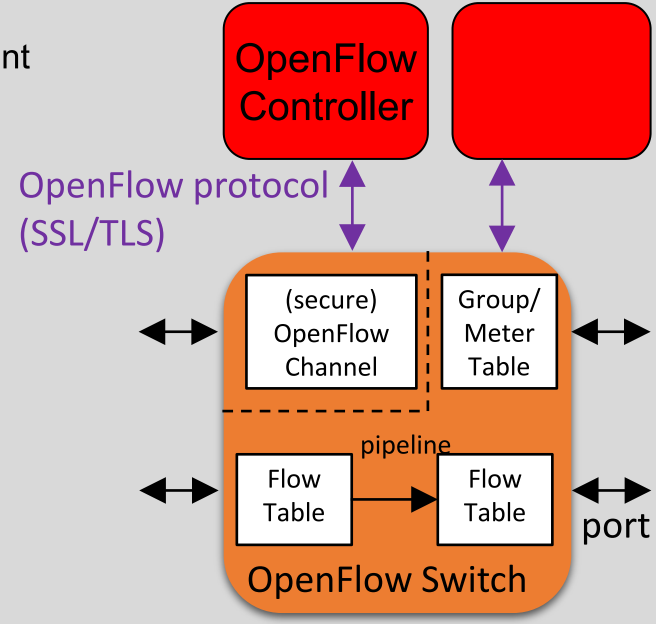
- Match: IP addresses and TCP/UDP port numbers
- Action: permit or deny

**Network Address Translator**

- Match: IP address and port
- Action: rewrite address and port

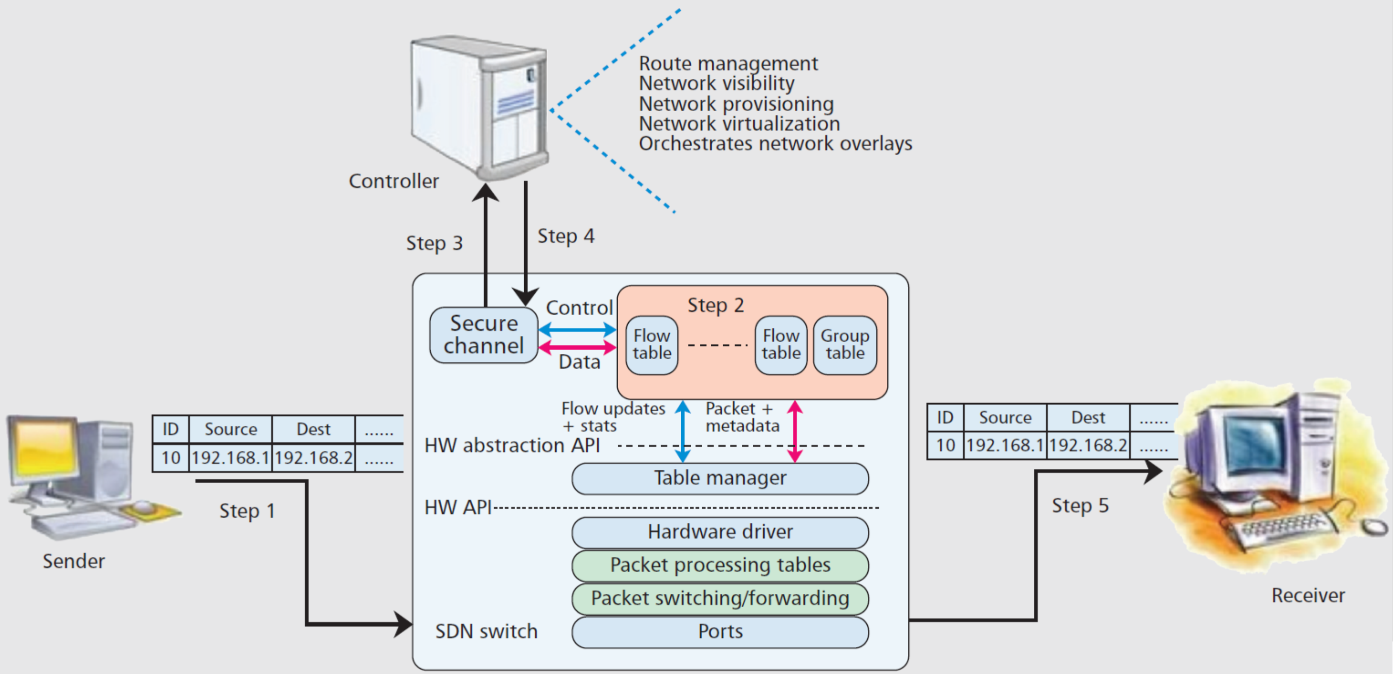
# 3. OpenFlow

- Current version: 1.5
- Most Ethernet switches and routers contain flow tables based on content addressable memory running at line-rate to
  - support QoS
  - implement firewalls and NATs
  - collect statistics
- Switches and routers provide similar functionality, but have proprietary flow tables (data path = flow table + actions).
- OpenFlow aims to provide a standard interface to program flow tables.
- OpenFlow Switch
  - Flow / group / meter tables
  - Secure channel for configuration
  - OpenFlow protocol
- OpenFlow Controller
  - adds / changes / removes table entries.



# 3. OpenFlow

## 1. Operation



| ID | Source | Dest | ...... |
|---|---|---|---|
| 10 | 192.168.1 | 192.168.2 | ...... |

| ID | Source | Dest | ...... |
|---|---|---|---|
| 10 | 192.168.1 | 192.168.2 | ...... |

# 3. OpenFlow

## 2. Flow Table

| | | | | | | |
|---|---|---|---|---|---|---|
| Match fields | Priority | Counter | Instructions | Timeouts | Cookie | Flags |

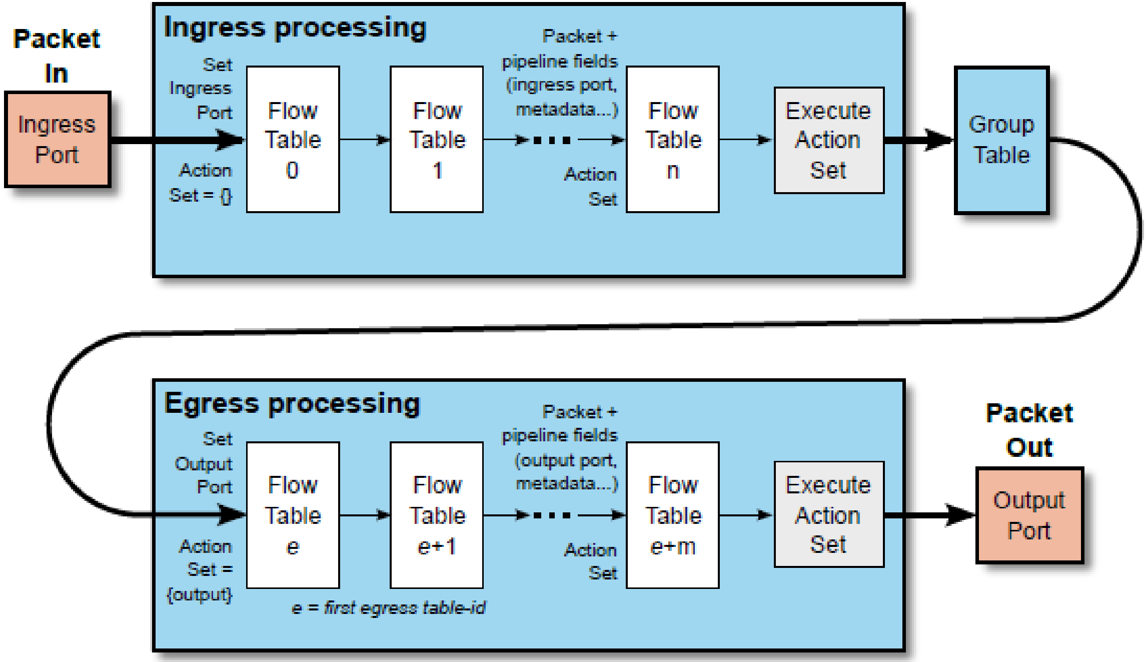
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Switch port | MAC src | MAC dst | Eth type | VLAN ID | VLAN prio | MPLS label | MPLS traffic cl. | IP src | IP dst | IP proto | IP ToS | src port | dst port |

- Match fields: to match against packets, consisting of ingress port and packet headers, and optionally metadata
- Priority:
  matching precedence of flow entry
- Counters:
  updated when packets are matched
- Instructions: to modify action set or pipeline processing
- Timeouts: maximum amount of time or idle time before flow is expired by switch
- Cookie:
  opaque data value chosen by controller
- Flags: to trigger certain reactions

# 3. OpenFlow

## 3. Packet Processing

≥ 1 ingress flow table



# 3. OpenFlow

## 4. Instructions

- Each flow table entry contains a set of instructions, which are executed when a packet matches the entry.
- Instructions change packet, action set and / or pipeline processing (directing packet to other flow table).

**Required instructions**

- Write-Actions: merges specified action into current action set
- Goto-Table: indicates next table in processing pipeline
- Clear-Actions: clear all actions immediately

**Optional instructions**

- Stat-Trigger: Generate event to controller, if some flow statistics exceed threshold values.
- Apply-Actions: applies specified actions immediately
- Write-Metadata: write masked metadata value into metadata field

# 3. OpenFlow

## 5. Actions and Action Sets

### Actions

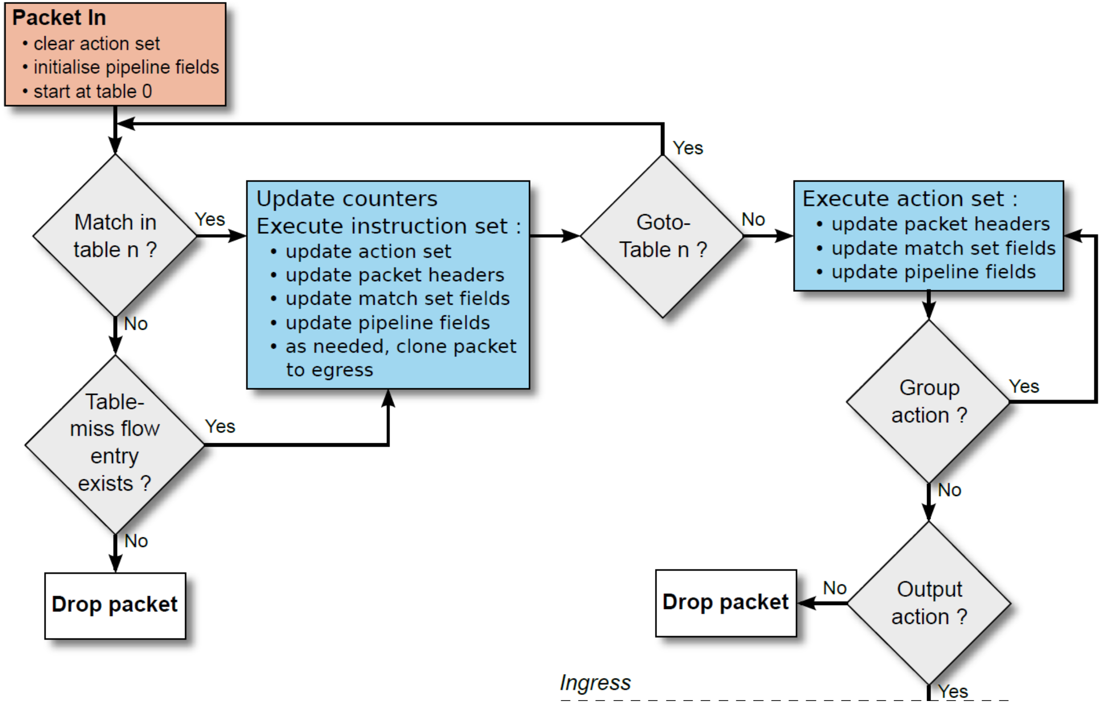
- Decrementing / copying TTL values
- Pop / push tags (MPLS, VLAN headers)
- Set MAC / IP addresses, VLAN IDs, port numbers, IP header bits etc.
- Quality-of-service actions, e.g., assign queues or meters to a packet
- Group actions
- Output of packets

### Action Sets

- are associated with each packet and are empty at the beginning for ingress processing and an output action for output processing.
- Flow entry instructions modify action set.
- Execution of actions at the end of pipeline, exception: Apply-Actions

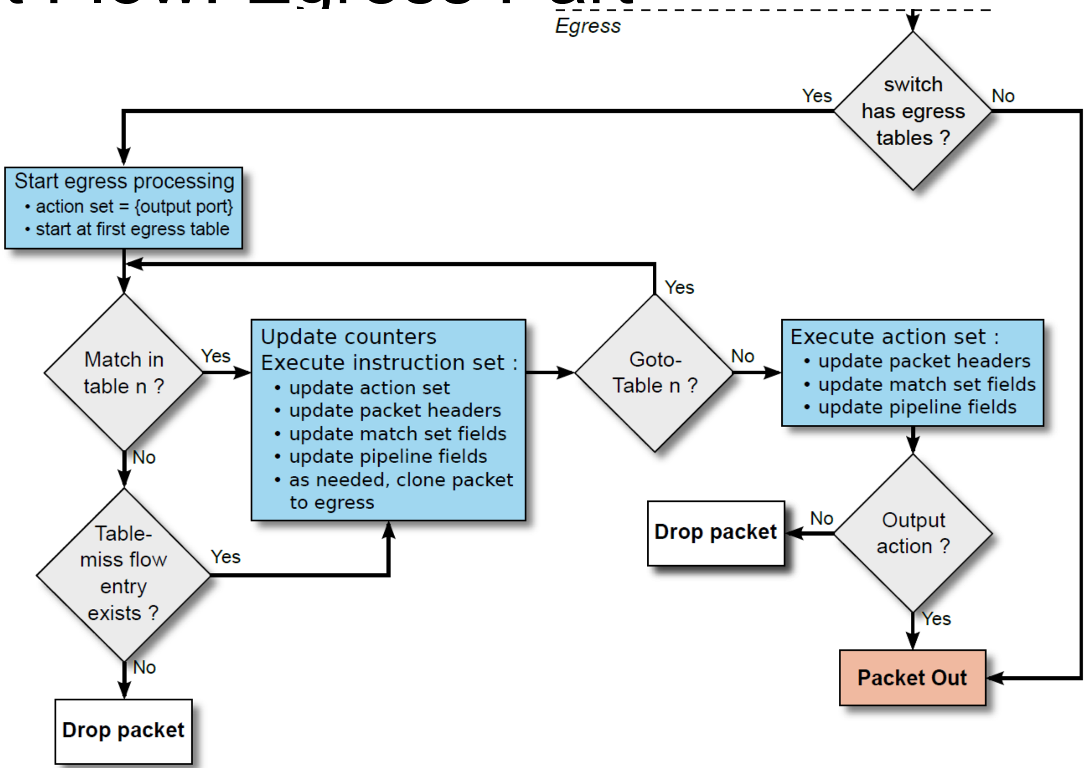
# 3. OpenFlow

## 6.1 Packet Flow: Ingress Part



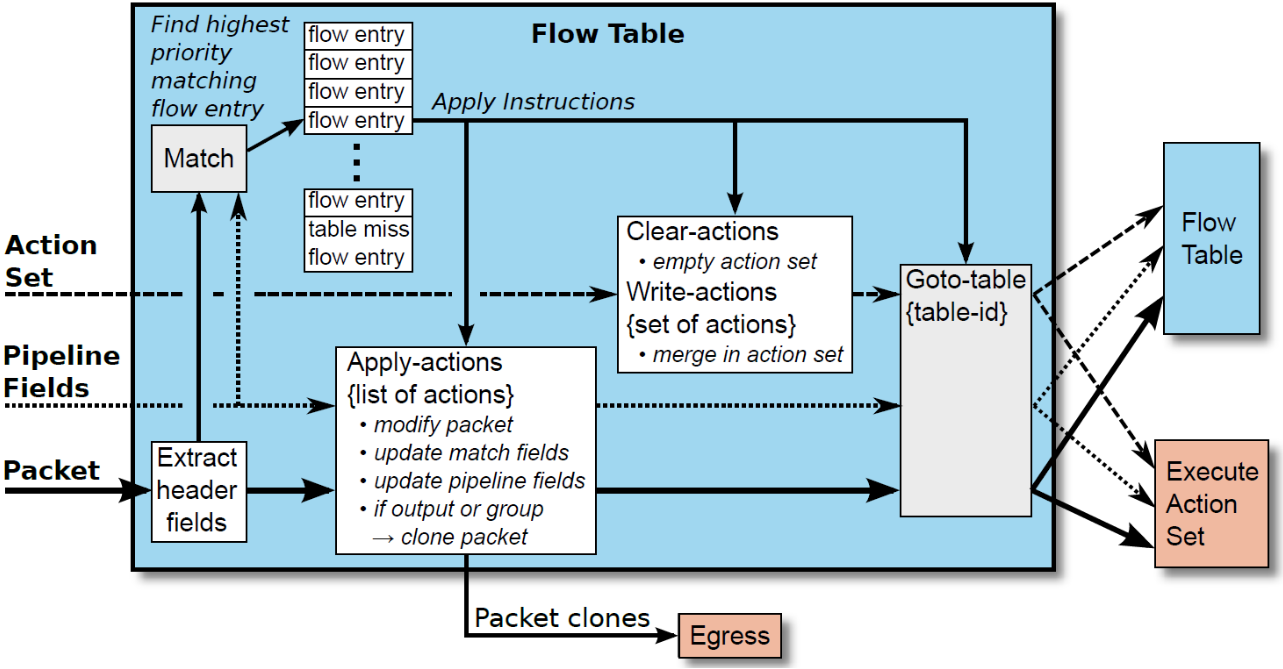
# 3. OpenFlow

## 6.2 Packet Flow: Egress Part



# 3. OpenFlow

## 7. Matching and Instruction Execution



# 3. OpenFlow

## 8. Group Table

- Group: list of Action Buckets and some means to choose one or more buckets per packet

| Group Identifier | Group Type | Counters | Action Buckets |
|---|---|---|---|

- Group table entry
  - Group Identifier: 32 bit unsigned integer uniquely identifying the group
  - Group Type: to determine group semantics
    - All: execute all buckets, multicast or flooding (required)
    - Indirect: one bucket, simple indirection (required)
    - Select: execute one bucket, for multipath forwarding and load balancing (optional)
    - Fast failover: execute first live bucket (optional)
  - Counters: updated when packets are processed by a group
  - Action Buckets: an ordered list of action buckets,
    where each Action Bucket contains a set of actions to execute and associated parameters

# 3. OpenFlow

# 9. Meter Table

## Meter Table Entry

- Meter bands define how packets are processed if target rate is exceeded.

| | | |
|---|---|---|
| Meter Identifier | Meter Bands | Counters |

## Applications

- Quality of Service operation
- Rate limiting and policing
- Metering
- Packet classification

# 3. OpenFlow

## 10. Protocol

**Message types**

- Controller-to-switch to
  - request switch features
  - set and query configuration parameters
  - add, modify, delete flow / group / meter table entries
  - read switch statistics
  - output packets to switch
  - set role of controller in case of multiple controllers (master / slave)
  - set filter for asynchronous messages
- Asynchronous: unsolicited messages from switch to controller to
  - receive packets
  - indicate flow removal after timeout
  - indicate port, role, table, controller status
- Symmetric (without solicitation in either direction)
  - Hello messages
  - Echo messages
  - Error messages

**Connection setup**

- TLS/TCP connection

# 4. SDN Summary

## 1. Key Issues

- Separation of control plane from data plane
- Centralized controller and centralized view of the network
- Open interfaces between devices in control plane (controllers) and those in data plane (network devices)
- Network programmability by external applications

# 4. SDN Summary

## 2. Benefits

- Simpler centralized network management and control
  - increases network reliability
  - minimizes inconsistent configuration
- Improved automation and management by common APIs
- Abstraction of underlying network details from orchestration / provisioning systems and applications
- Rapid innovation independent from network device manufacturers
- Programmability by operators and users
- More fine-granular network control
- Simpler, faster, cheaper network devices

# 5. SDN Applications

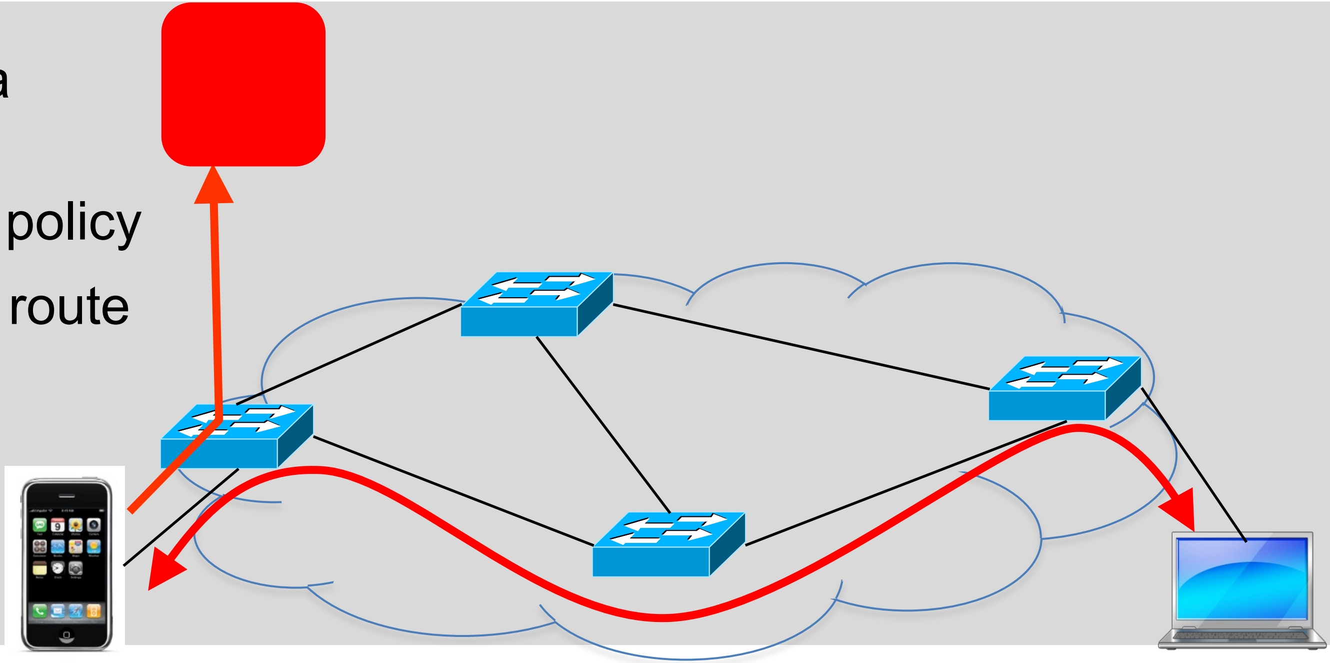
1. *Dynamic access control*
2. *Seamless mobility/migration*
3. *Server load balancing*
4. *Network virtualization*

- Link failure recovery
- Data centre networking
- Multiple wireless access points
- Energy-efficient networking
- Adaptive traffic monitoring
- Denial-of-Service attack detection
- Network management and control
- Virtual networks
- Non-IP networks, Future Internet protocols
- Deep-packet inspection, intrusion detection

# 5. Applications

## 1. Dynamic Access Control

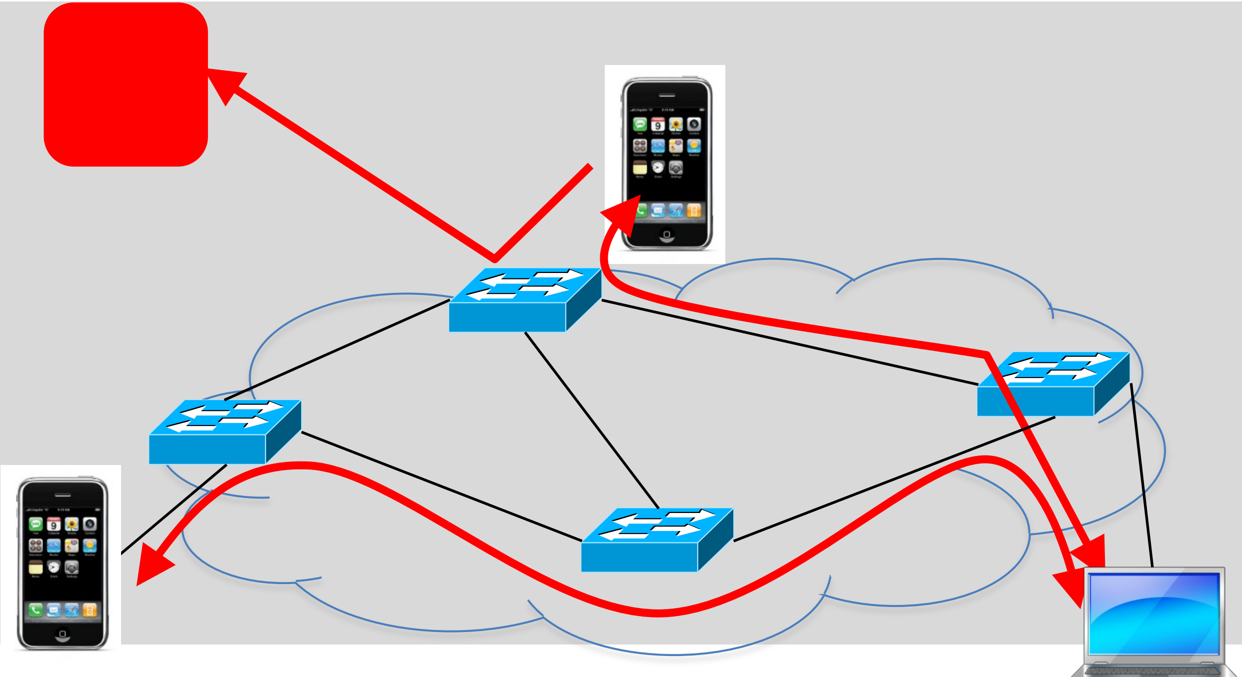
- inspect first packet of a connection
- consult access control policy
- install rules to block or route traffic



# 5. Applications

## 2. Seamless Mobility / Migration

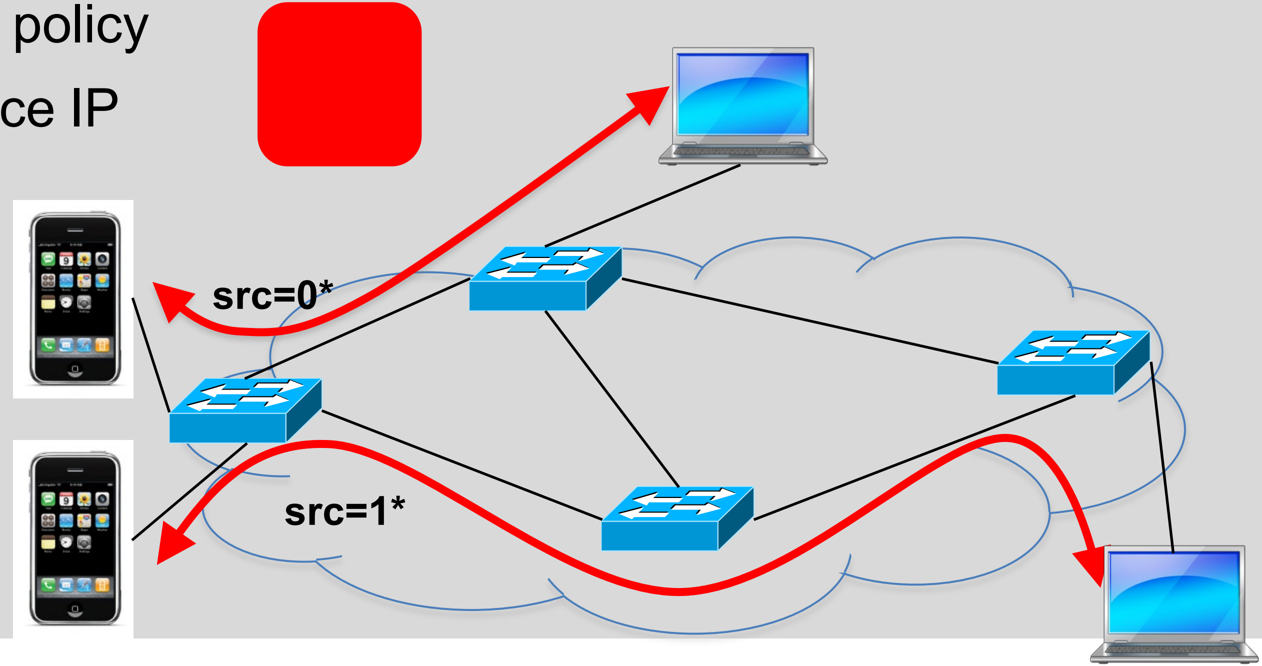
- see host to send traffic at new location
- modify rules to reroute traffic



# 5. Applications

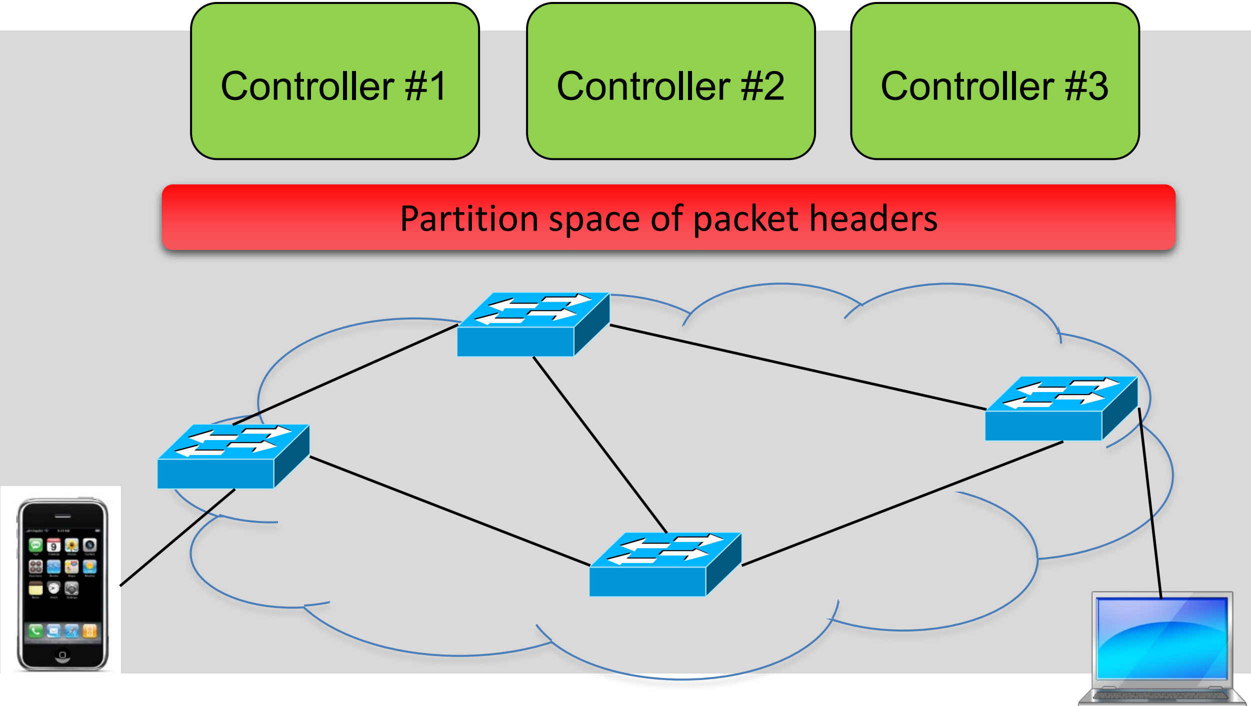
## 3. Server Load Balancing

- Pre-install load-balancing policy
- Split traffic based on source IP



# 5. Applications

## 4. Network Virtualization



# Thanks

## for Your Attention

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