CellSDN: Taking control of cellular core networks

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Joint work with Xin Jin, Li Erran Li, and Jennifer Rexford

Cellular core networks
are not **flexible**

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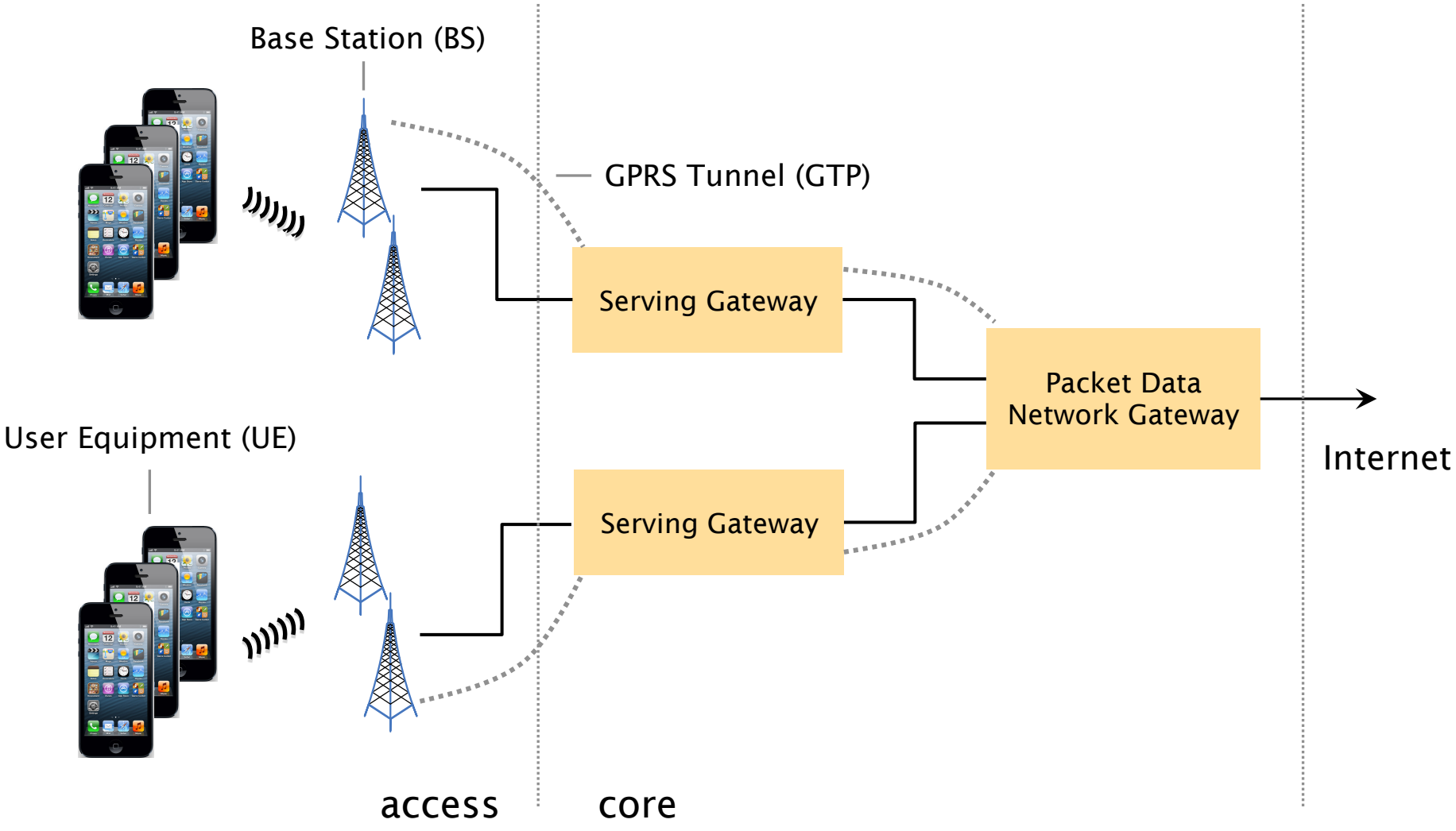

Cellular core networks are not **flexible**

Most functionalities are implemented at the PGW:

- Stateful firewall, DPI, lawfull intercept
- Application optimization
- Paging
- Monitoring and Billing

Packet Data Network Gateway

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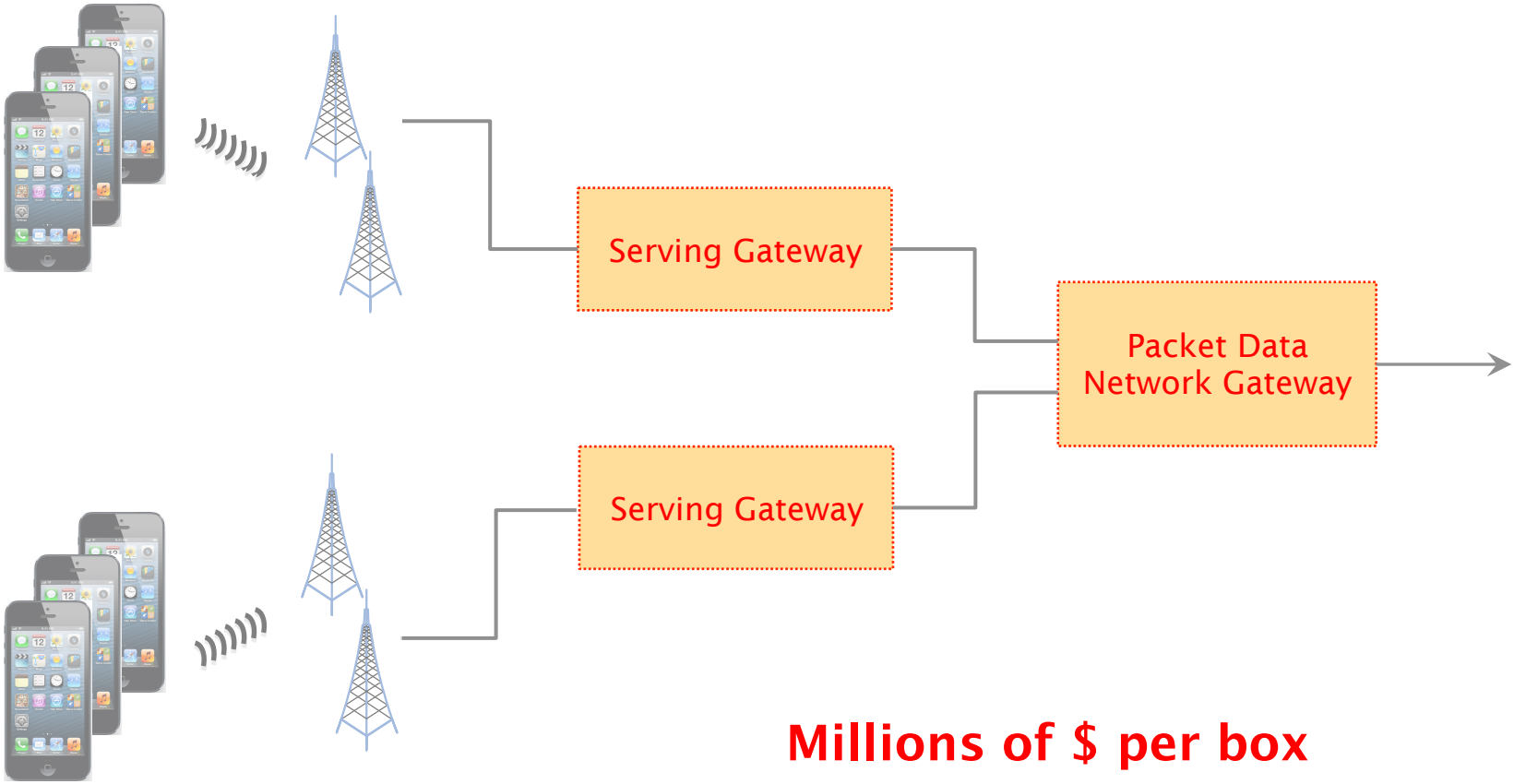
Packet Data Network Gateway

- **Hard to mix-and-match**
- **Slow innovation**

Cellular core networks are not flexible **and costly!**



CellSDN enables
flexible and cost-effective networks

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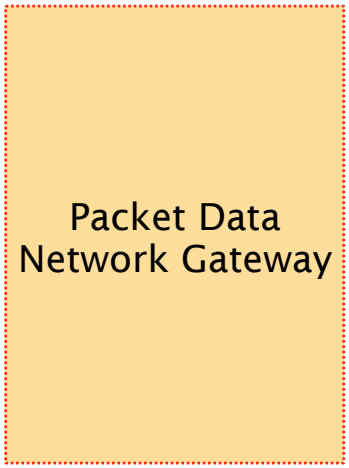
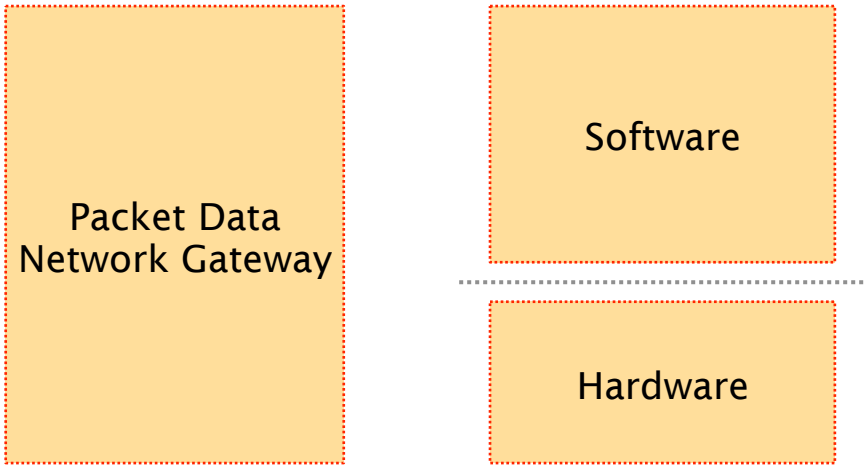
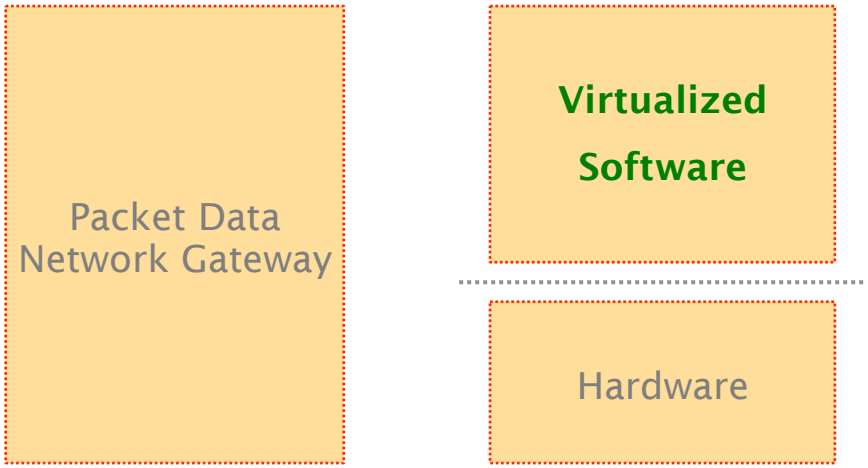
Key idea: separate Software from Hardware



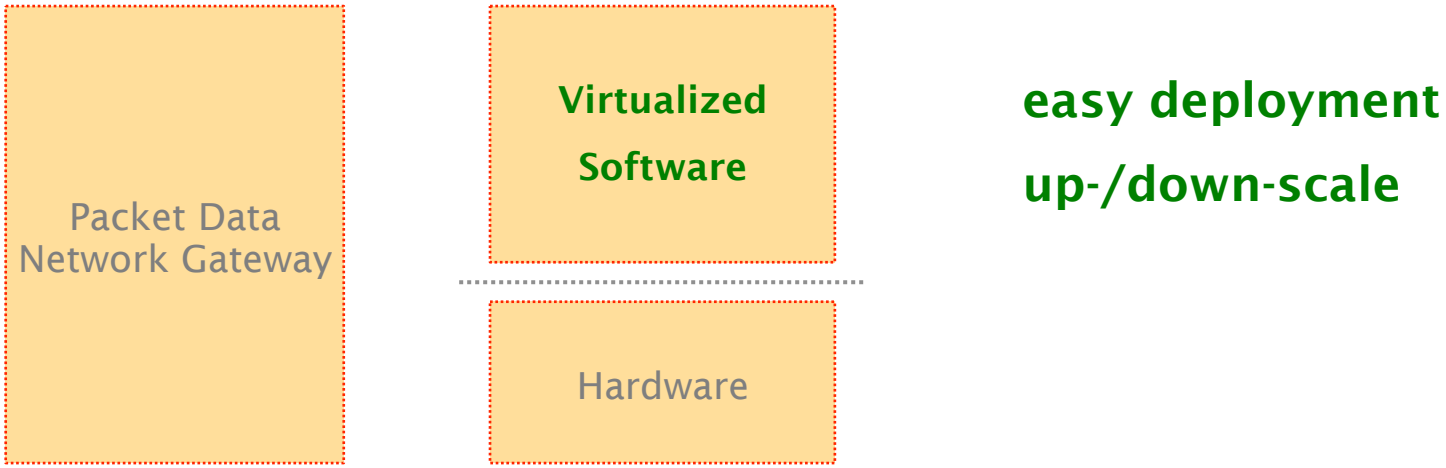
CellSDN enables flexible and cost-effective networks



CellSDN enables flexible and cost-effective networks



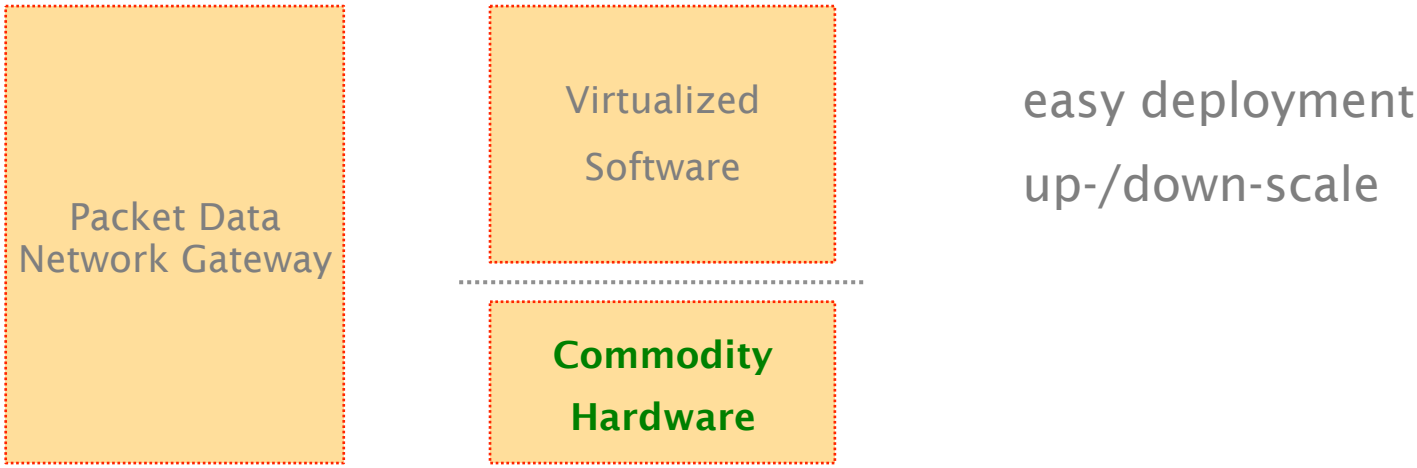
CellSDN enables **flexible** and cost-effective networks



easy deployment

up-/down-scale

CellSDN enables flexible and cost-effective networks



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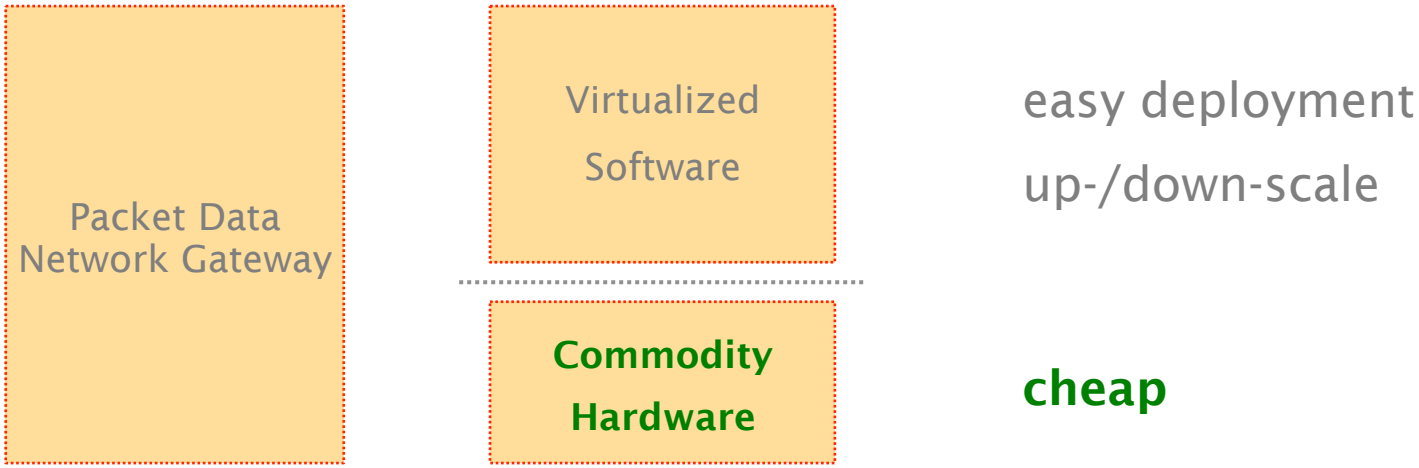
CellSDN enables flexible and **cost-effective** networks



To enable CellSDN flexibility, the challenge is **scalability**

Cellular policies are fine-grained, based on

- customer-attributes
  smartphone model, OS, billing plan, …
- applications
  video, web, voice, …
- a combination of both
  video from iPhone 5 gold subscribers, …

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  smartphone model, OS, billing plan, …
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can lead to *million* of different flows

To enable CellSDN flexibility, the challenge is **scalability**

	Challenges
Data-plane	Forwarding table size
Control-plane	Overhead
	Slow reactivity

To enable CellSDN flexibility, the challenge is **scalability**

	Challenges	Solutions
Data-plane	Forwarding table size	**Hierarchical tagging**
Control-plane	Overhead	
	Slow reactivity	

To enable CellSDN flexibility, the challenge is **scalability**

	Challenges	Solutions
Data-plane	Forwarding table size	Hierarchical tagging
Control-plane	Overhead Slow reactivity	**Hierarchical controller**

CellSDN: Taking control of cellular core networks

Architecture

software-defined network

Scaling the data-plane

multi-dimensional tagging

Scaling the control-plane

tasks delegation

CellSDN: Taking control of cellular core networks

1 Architecture

software-defined network

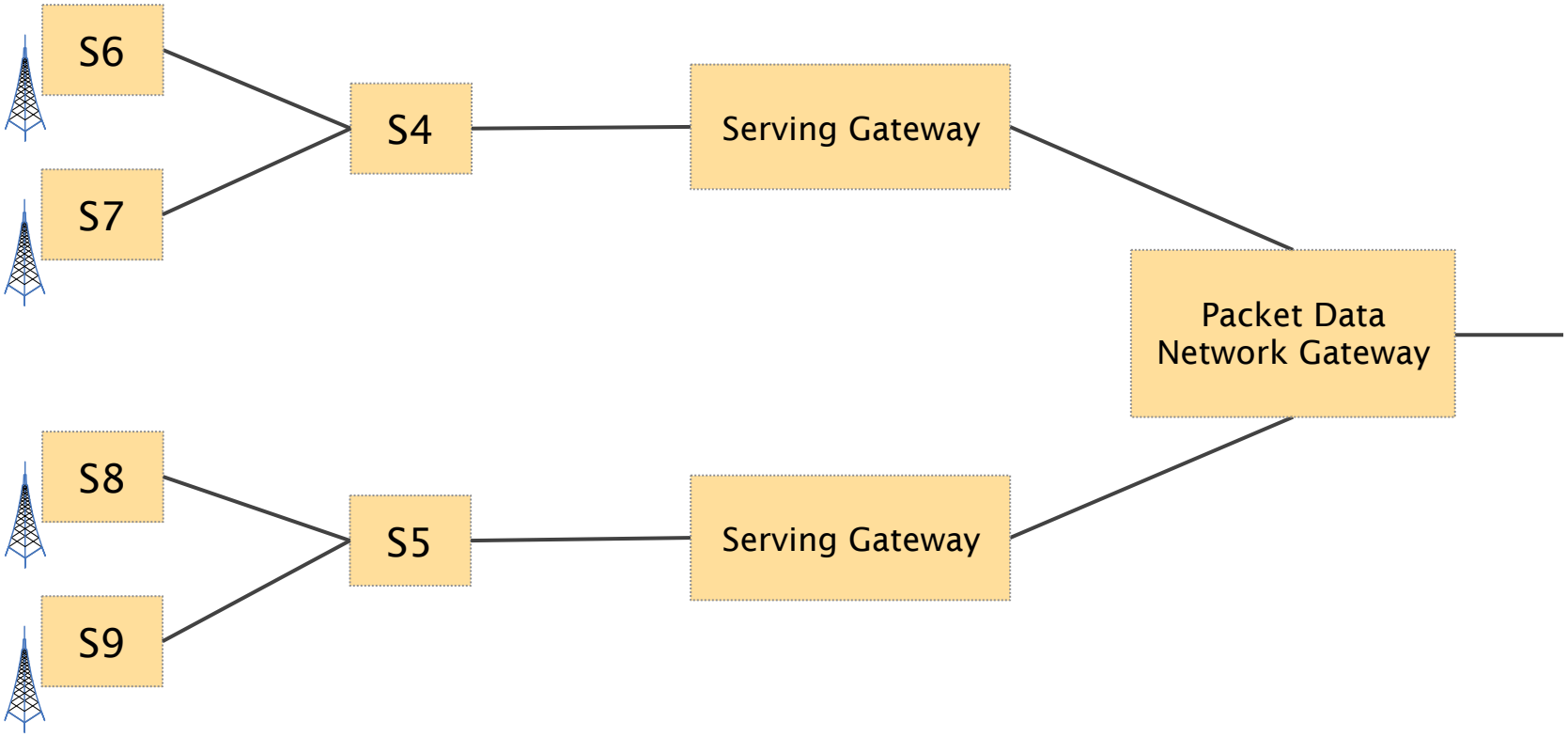
Scaling the data-plane

multi-dimensional tagging

Scaling the control-plane

tasks delegation

CellSDN relies on commodity, SDN-enabled switches



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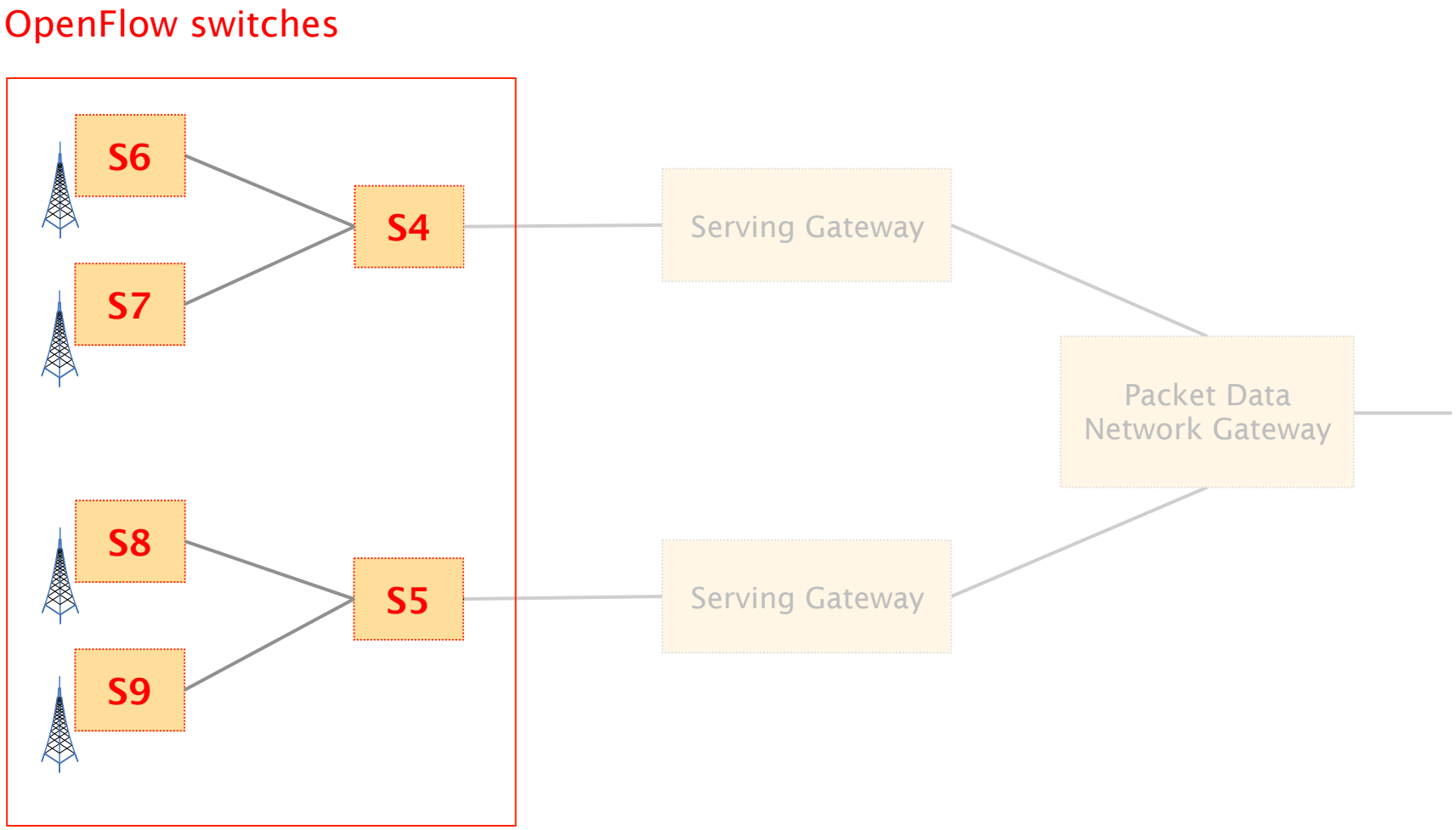
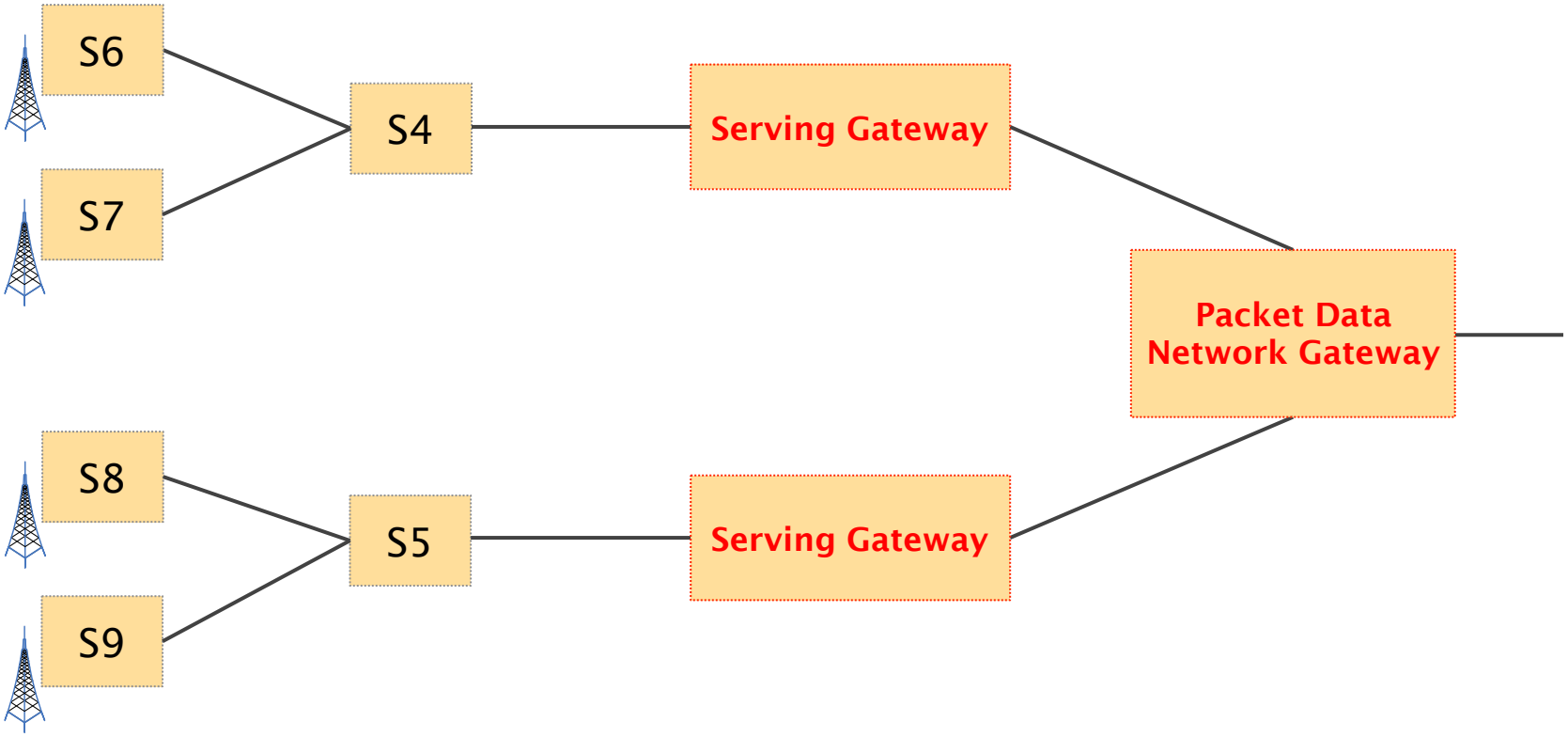


CellSDN also relies on commodity SDN switches *for specialized appliances*



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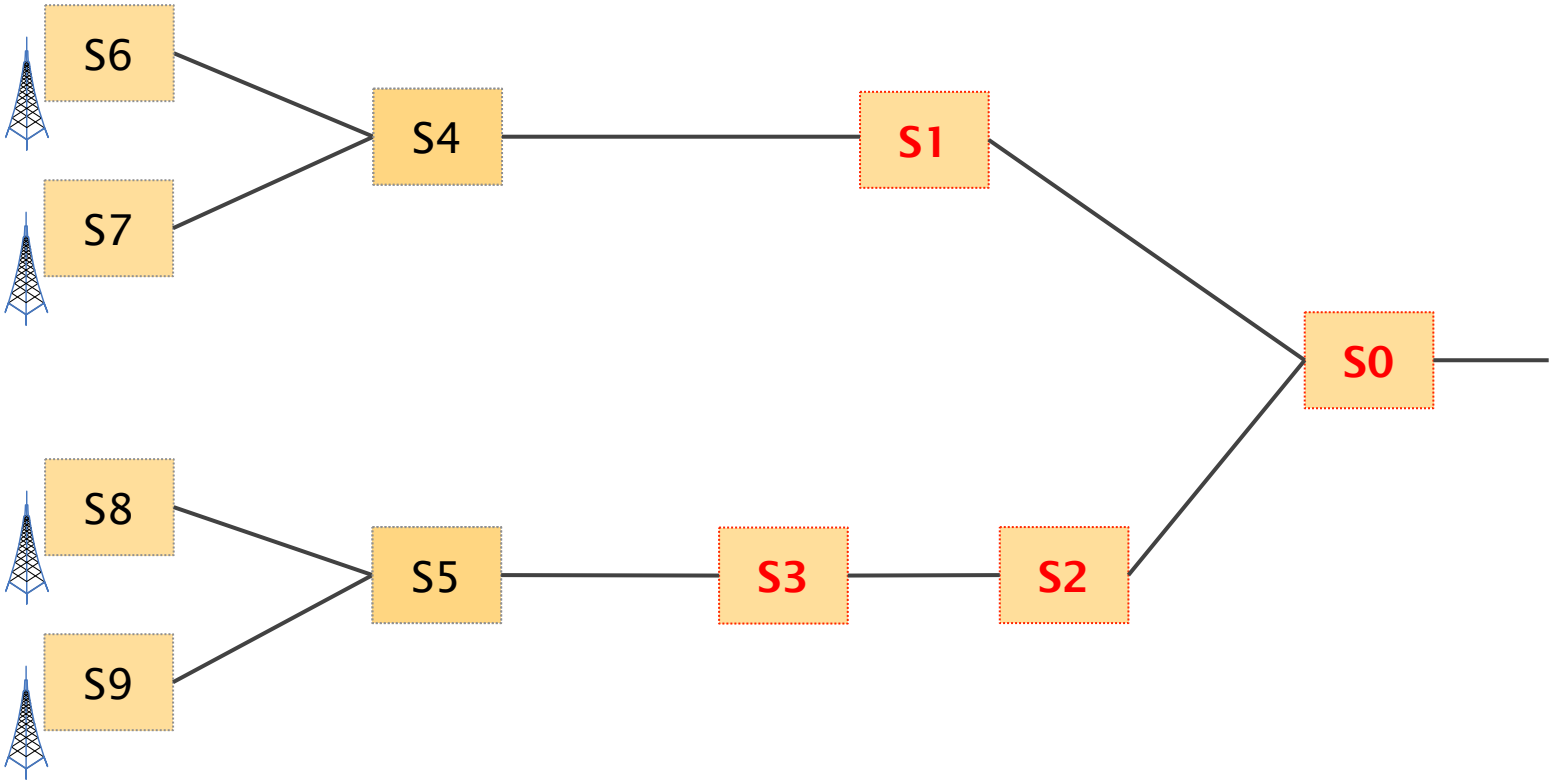
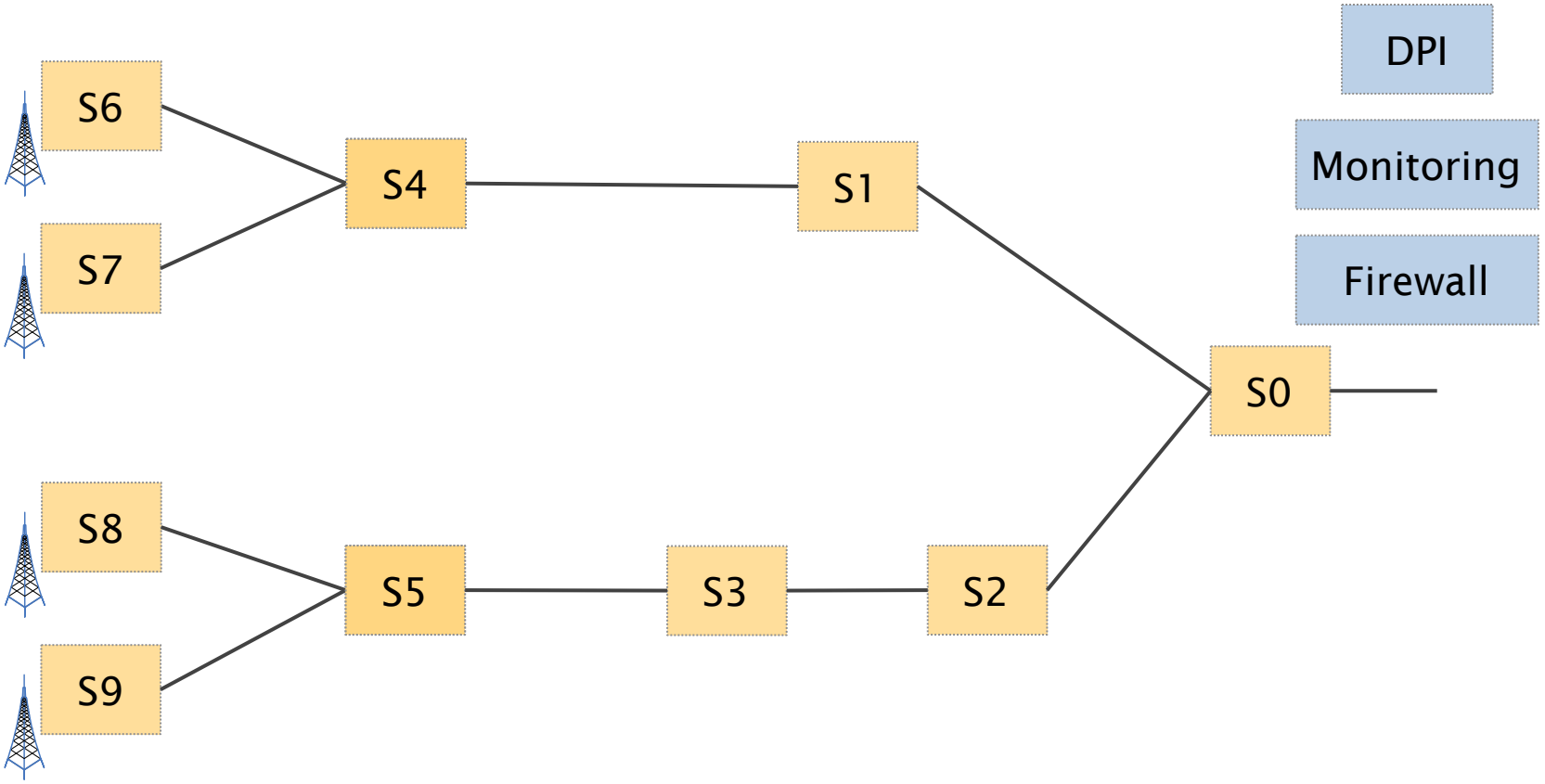
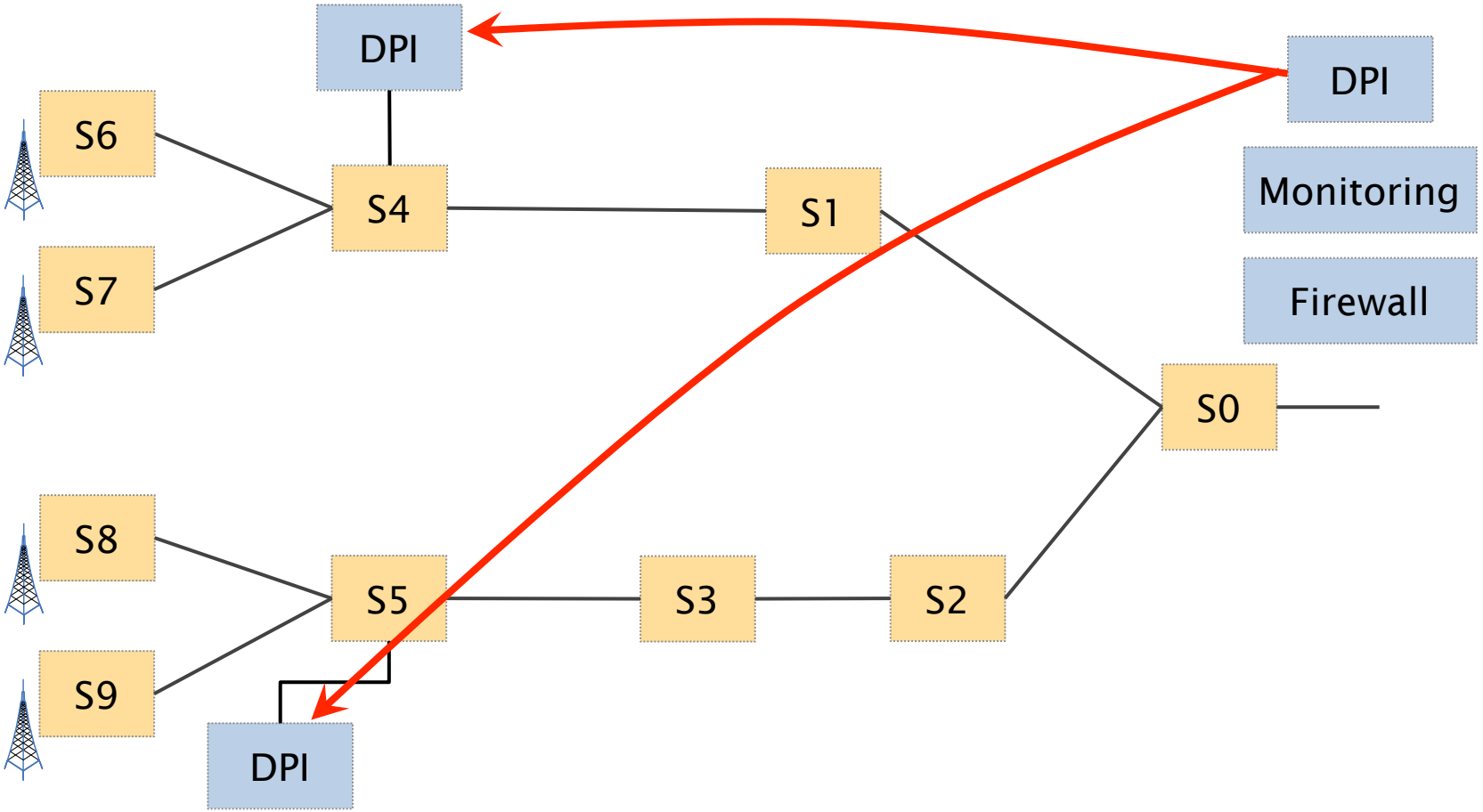
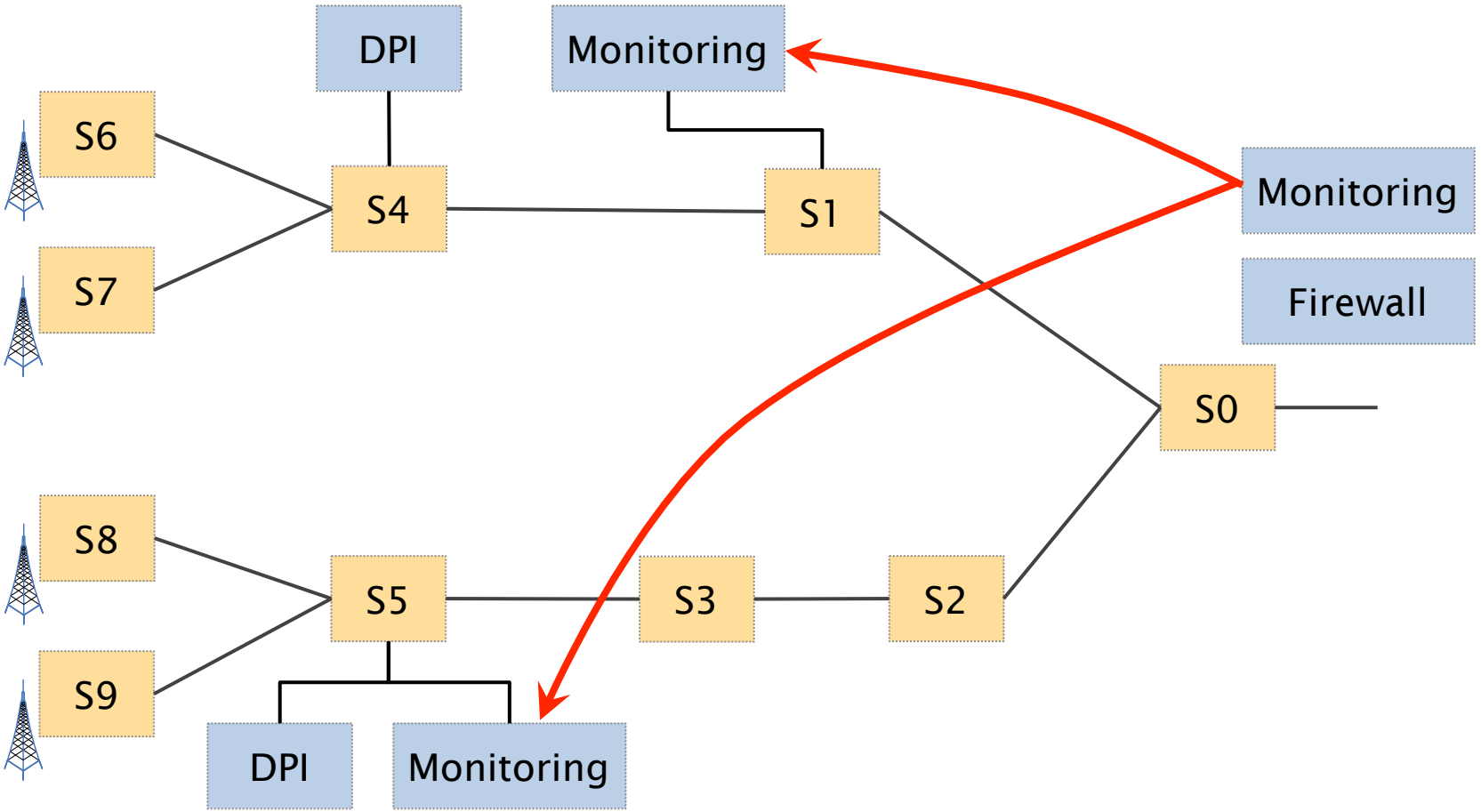


CellSDN distributes network processing




DPI
DPI
Monitoring
Firewall
S6
S7
S4
S1
S0
S8
S9
S5
S3
S2
DPI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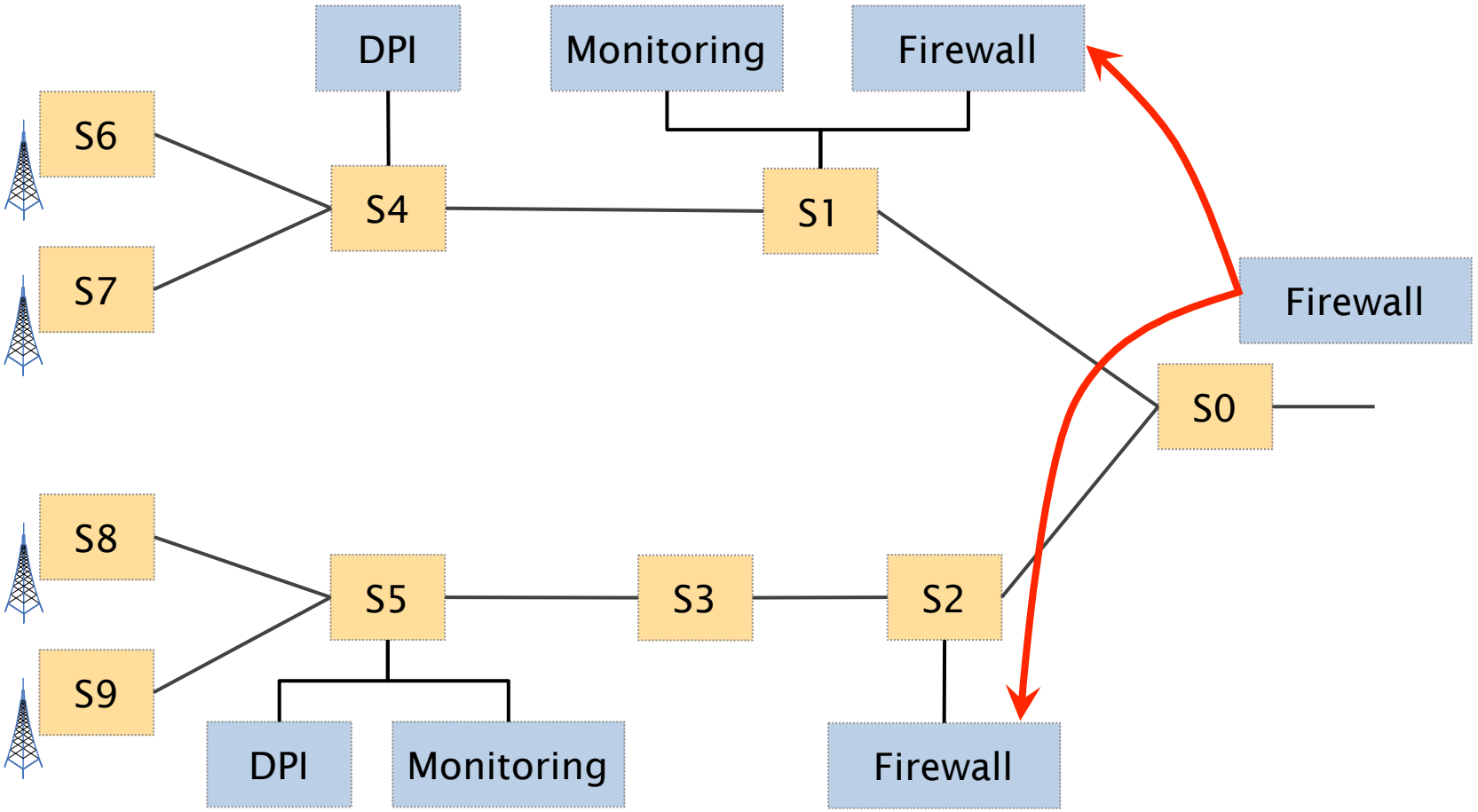
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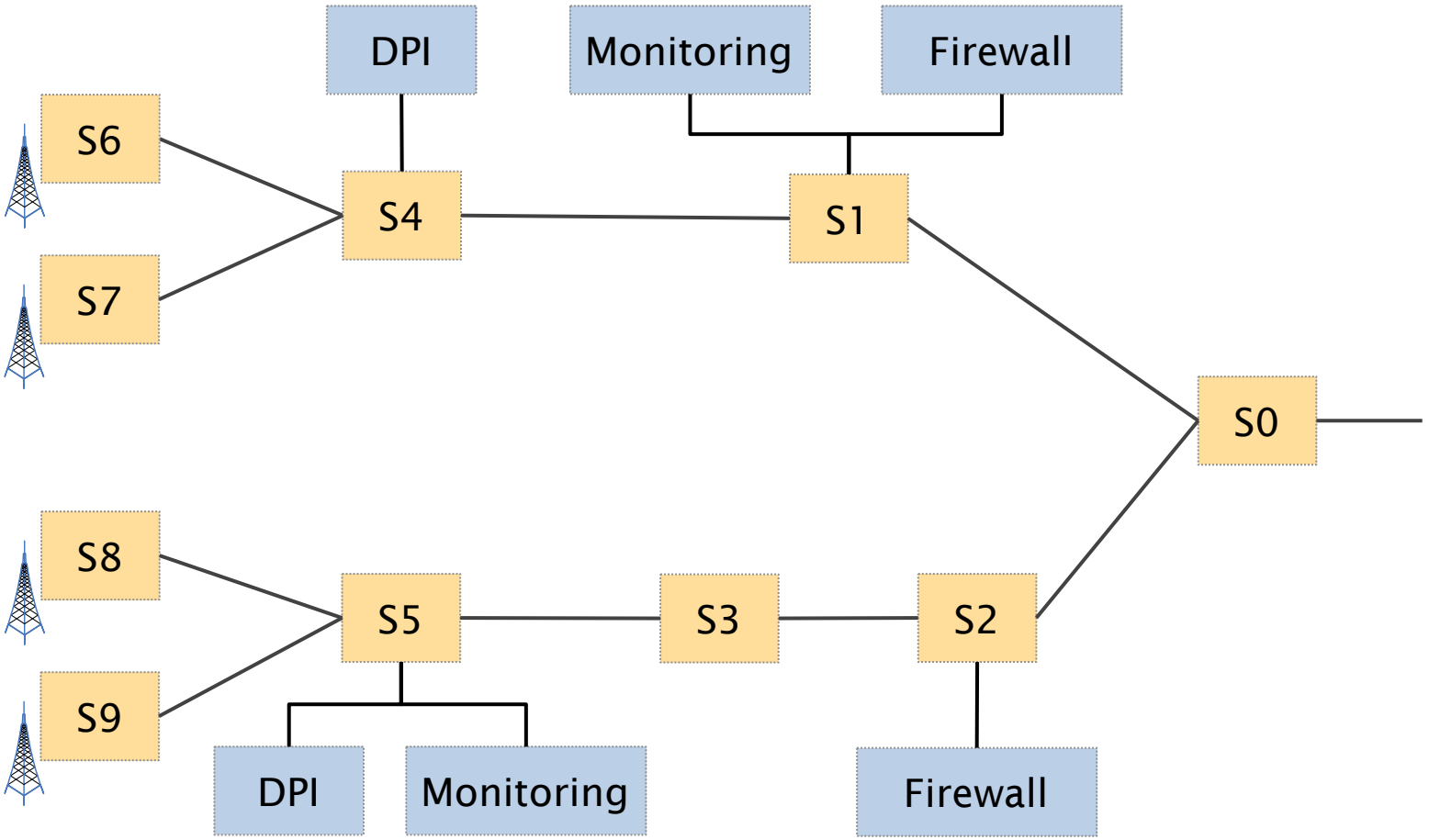
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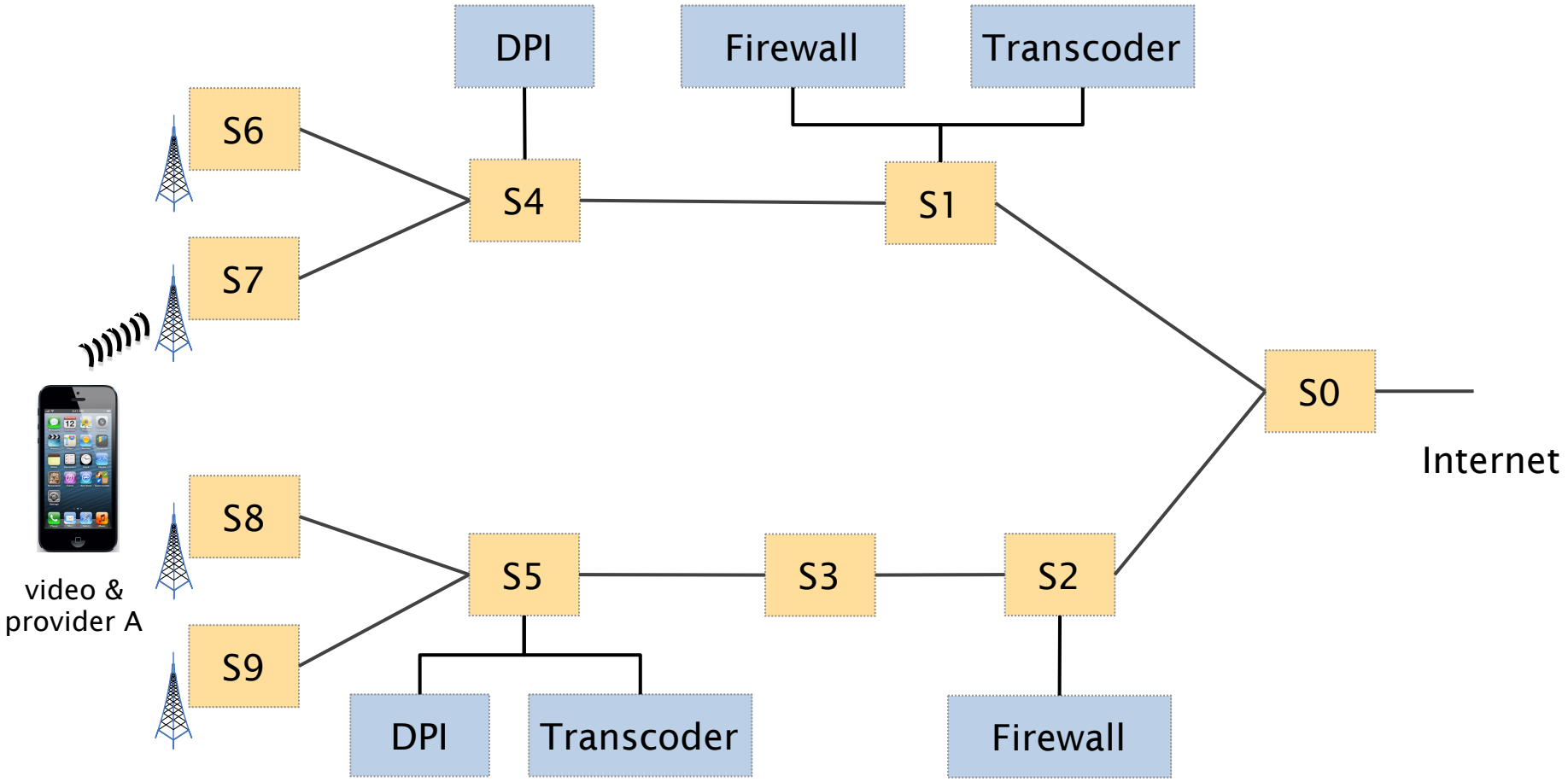
CellSDN route traffic based on high-level service policies

A service policy is composed of a

predicate	A boolean expression, e.g. on subscriber attributes, applications attributes, cell properties …
action	A list of middleboxes, access-control specifications (i.e., allow/deny) …
priority	An integer. To disambiguate overlapping policies

Example of service policy

priority	predicate	action
1.	provider is *B*	Firewall
2.	provider is not A	Drop
3.	traffic is video and plan is Silver	Firewall ⟶ Transcoder
4.	*	Firewall


DPI
Firewall
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S6
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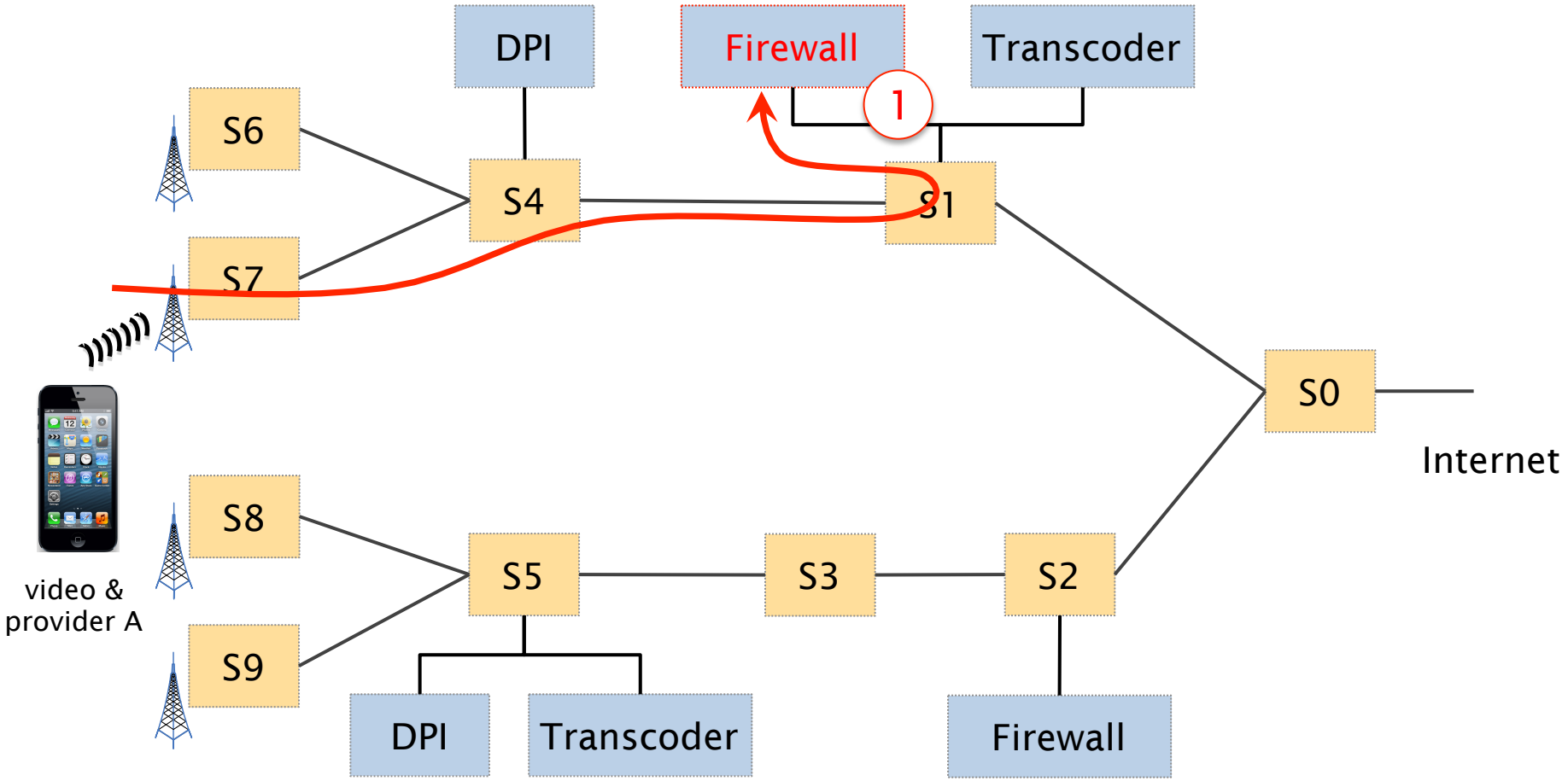
DPI
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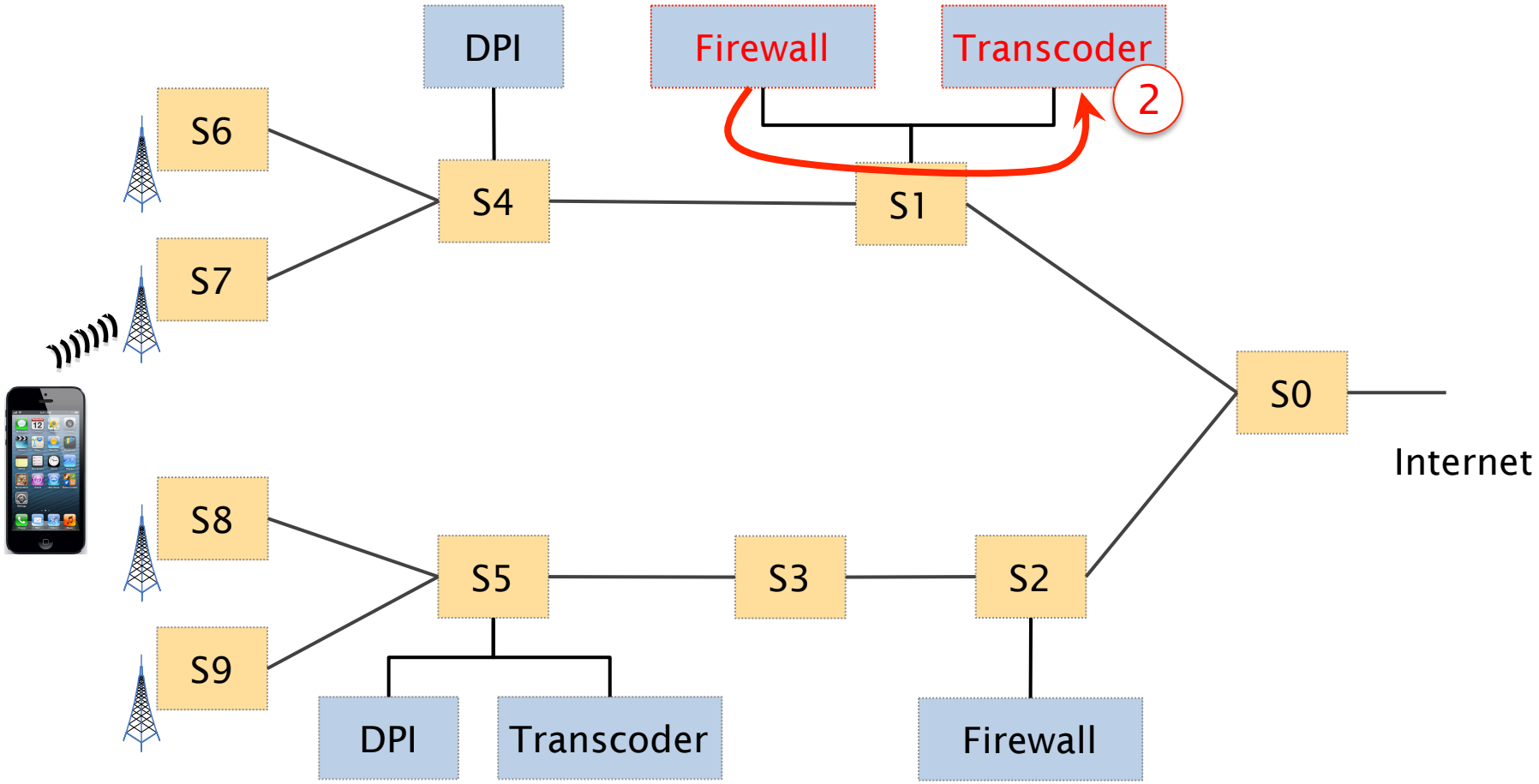
DPI
Firewall
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S6
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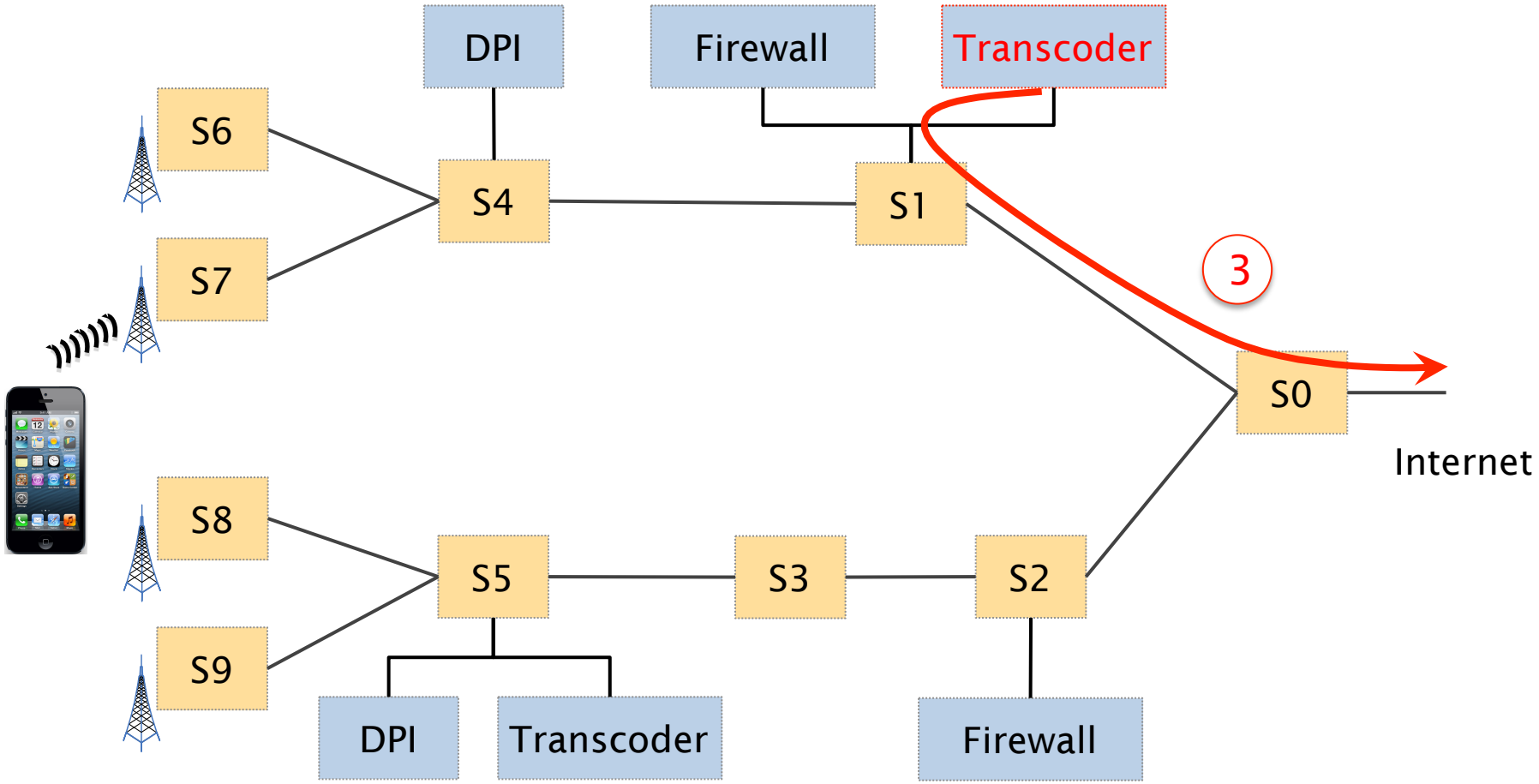
DPI
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S6
S4
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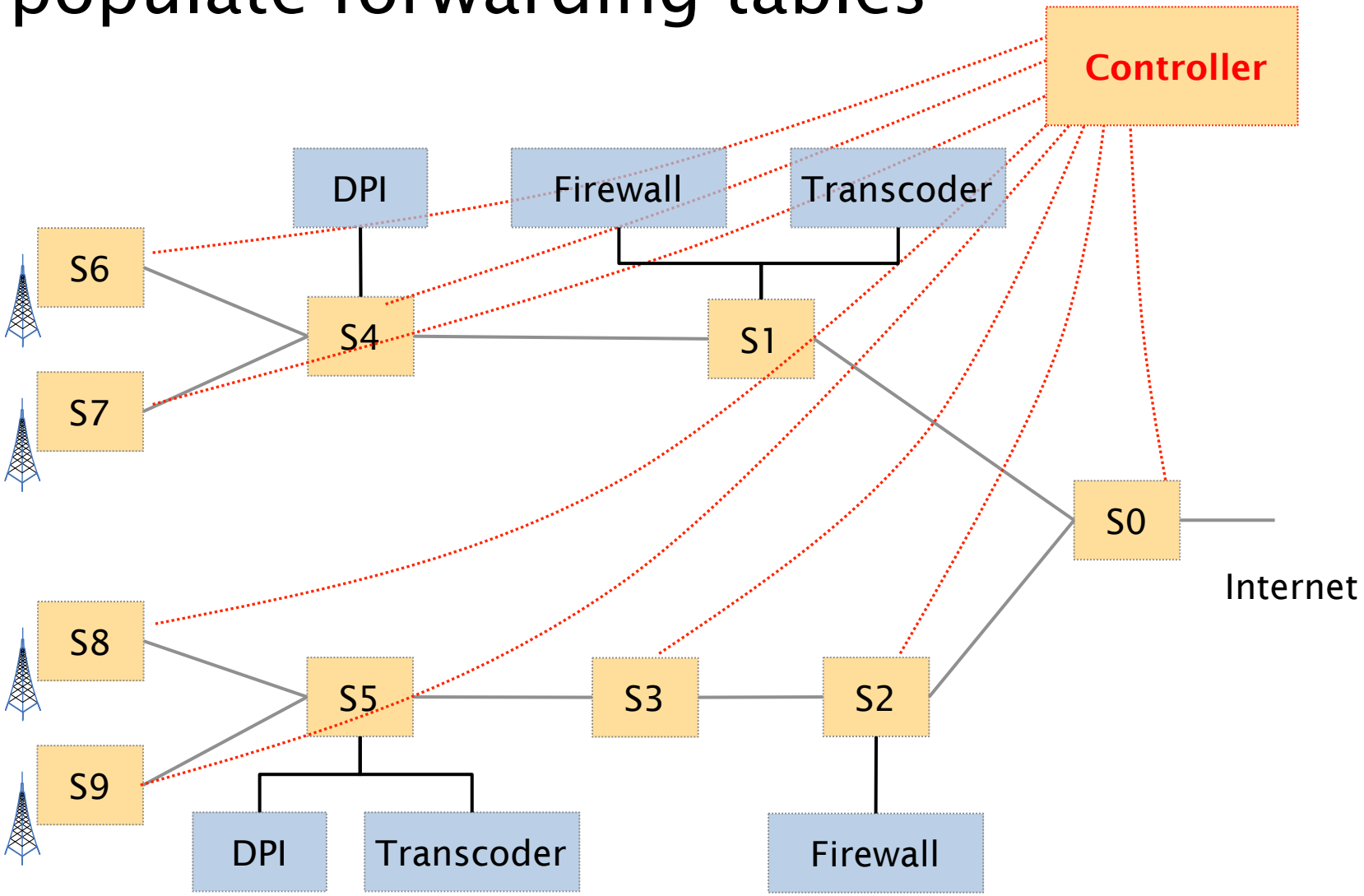
CellSDN uses a centralized controller to populate forwarding tables



CellSDN: Taking control of cellular core networks

Architecture

software-defined network

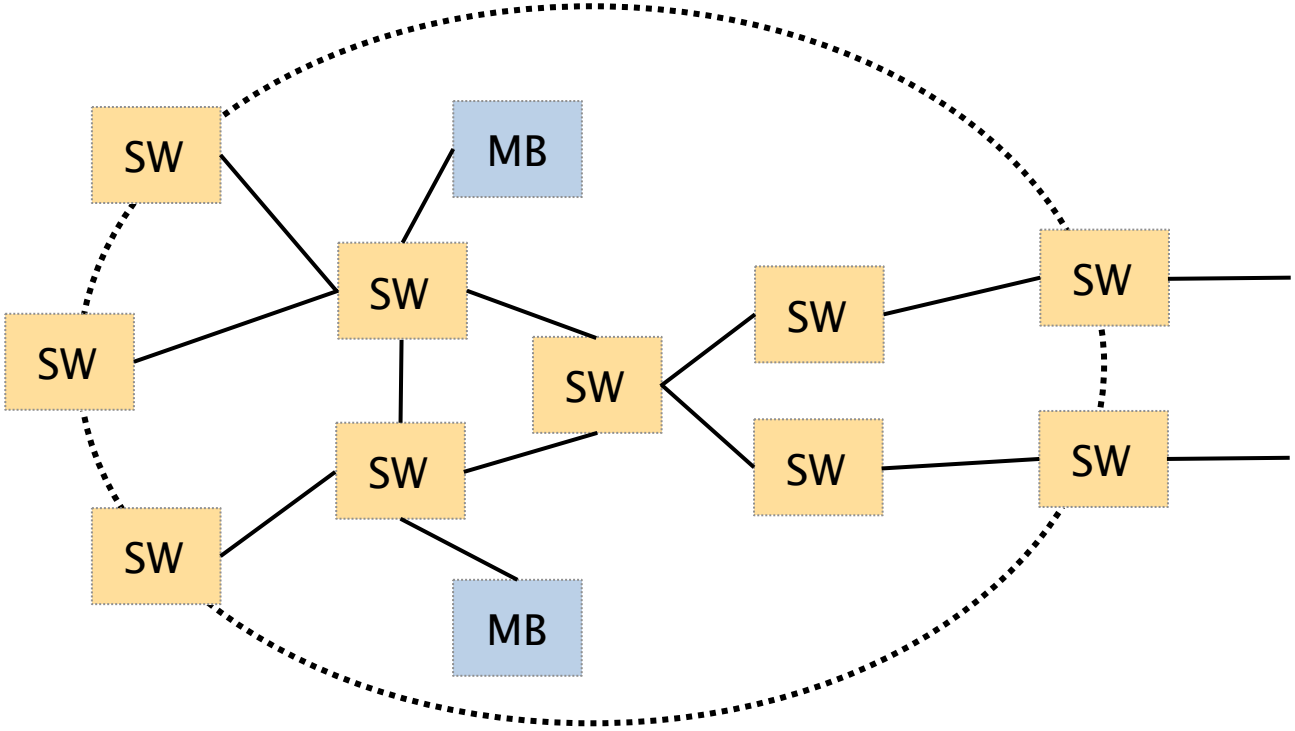
2 Scaling the data-plane

multi-dimensional tagging

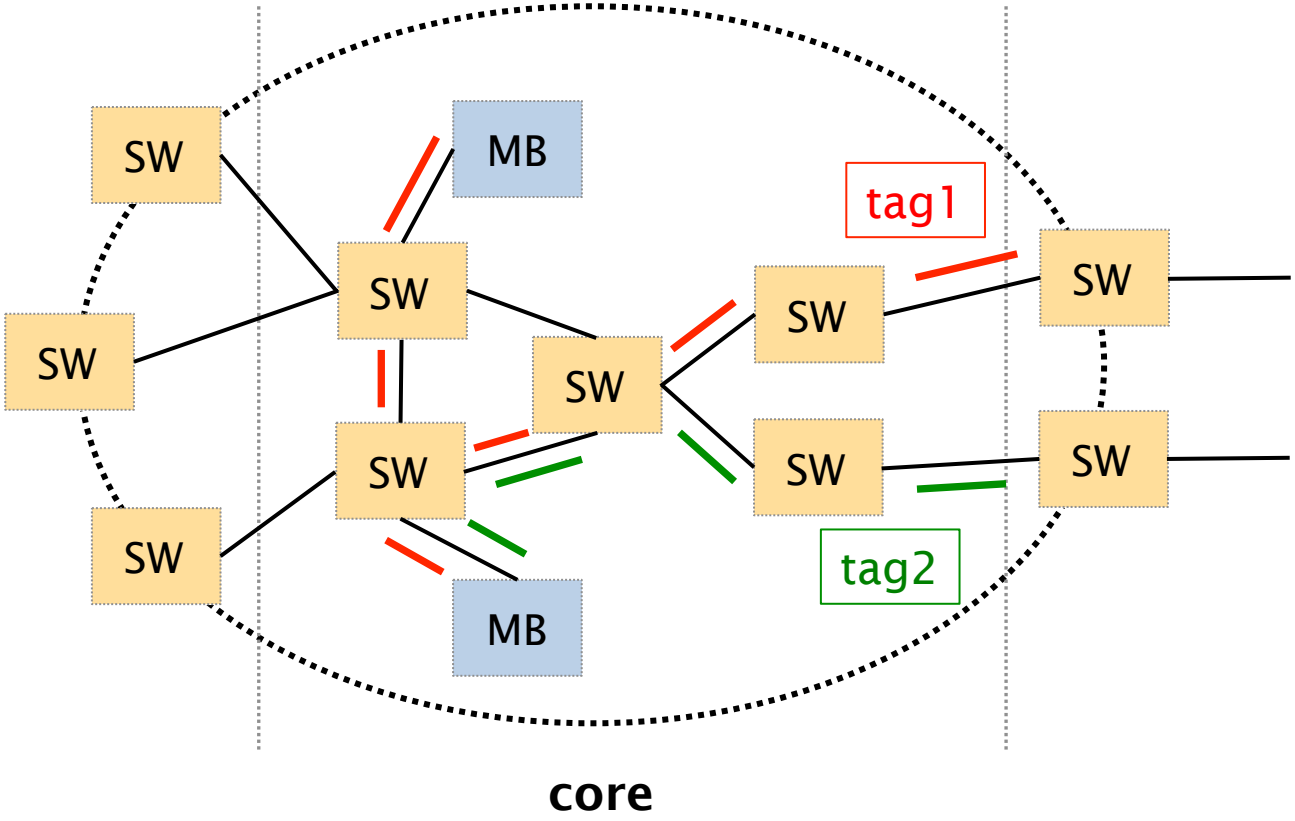
Scaling the control-plane

tasks delegation

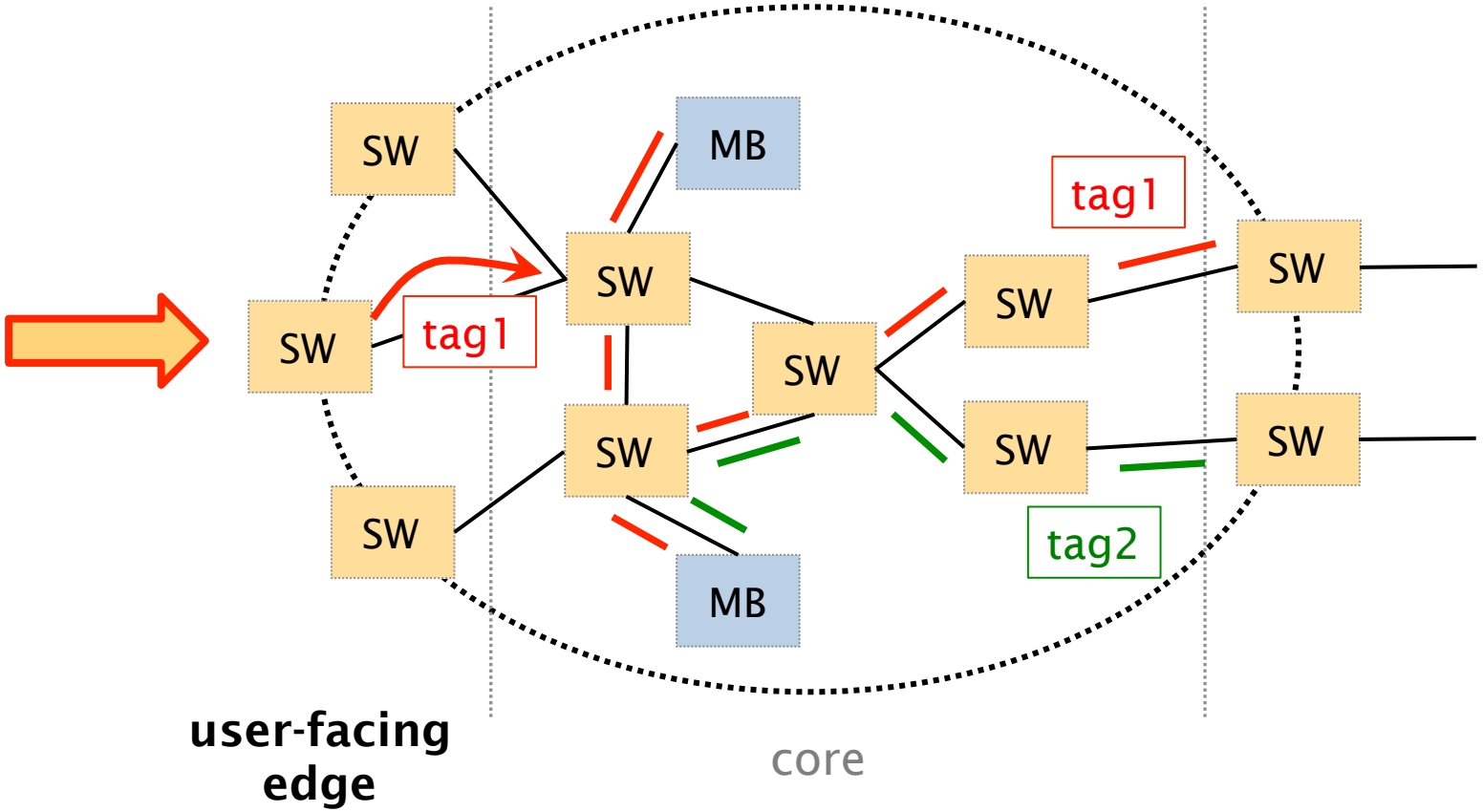
CellSDN relies on tagging to implement forwarding policies



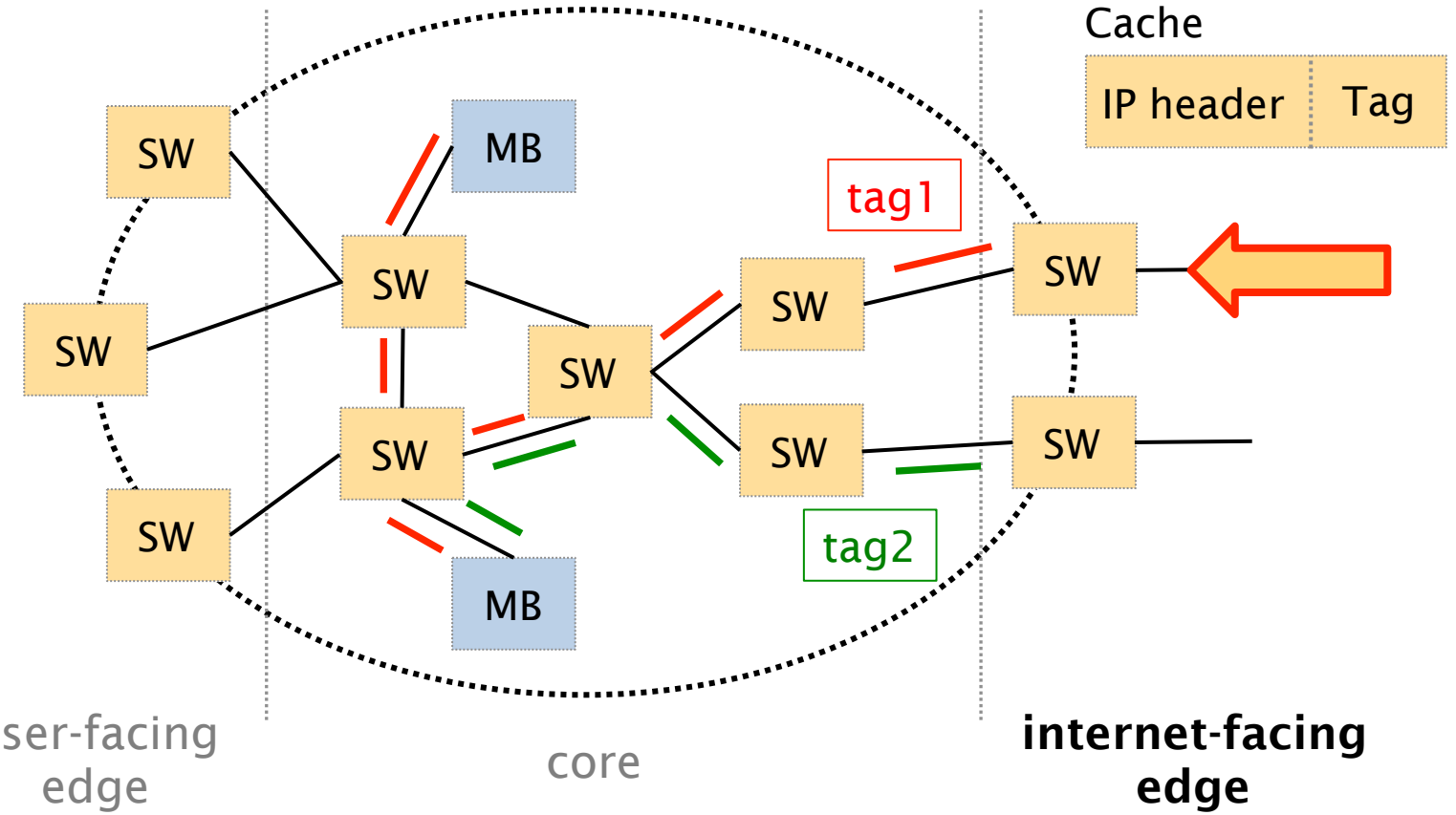
CellSDN installs stable policy path in the core



CellSDN classifies and tags traffic at the user-facing edge



CellSDN caches tags at the Internet-facing edge for the return traffic



If each path gets one tag, millions of tag are needed

1000	*	1000	=	**1 million**
# base station		# policy paths / base station		**# paths**

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1000	*	1000	=	1 million
# base station		# policy paths / base station		# paths

At best, switches support a few tens of thousands entries

[Stephen, Conext12]

CellSDN relies on multi-dimensional tag

CellSDN tags are composed of three parts:

- Policy
- Location
- User Equipment Identifier

switches can selectively match on any part

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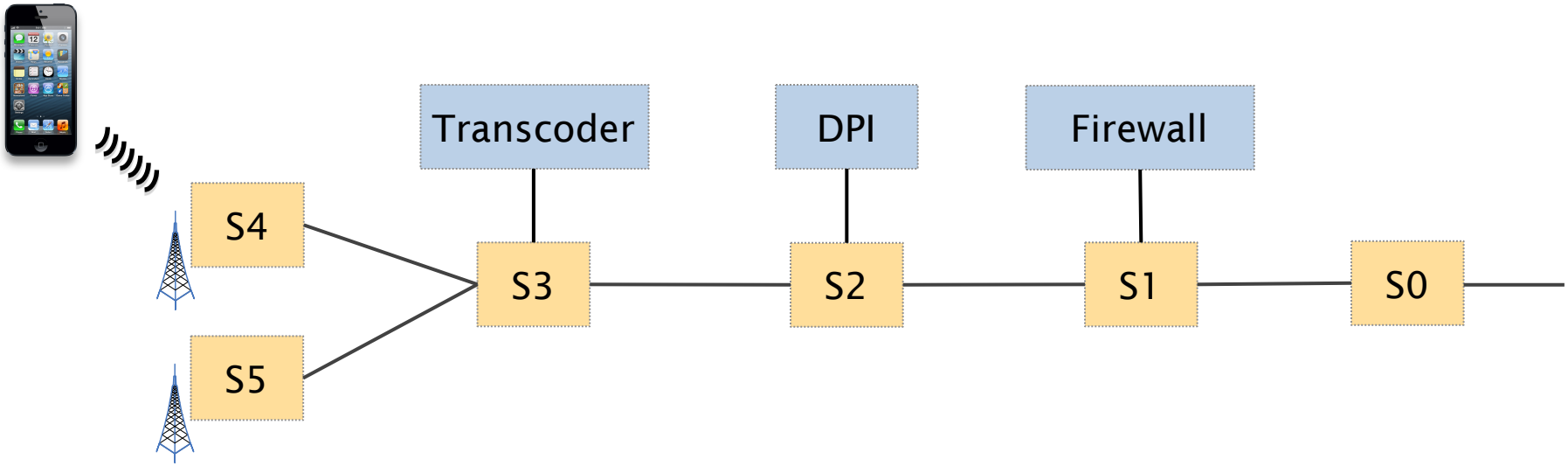
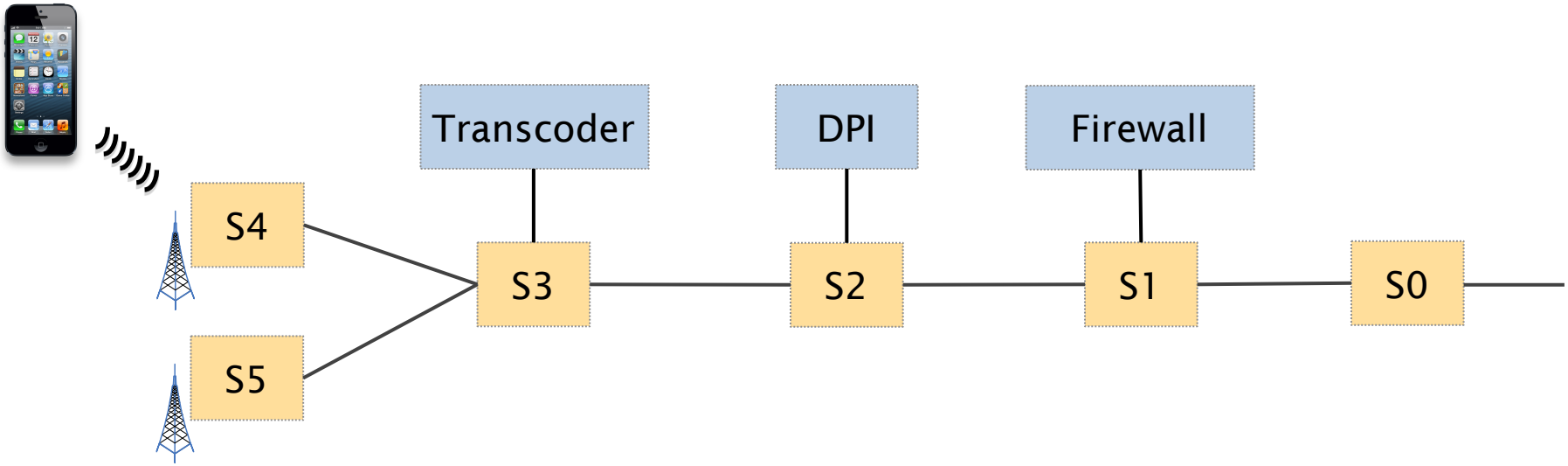
- **Policy**
- Location
- User Equipment Identifier

Video Traffic + Gold Membership = Transcoder || Firewall



Video Traffic + Gold Membership = **Transcoder || Firewall**

tag1



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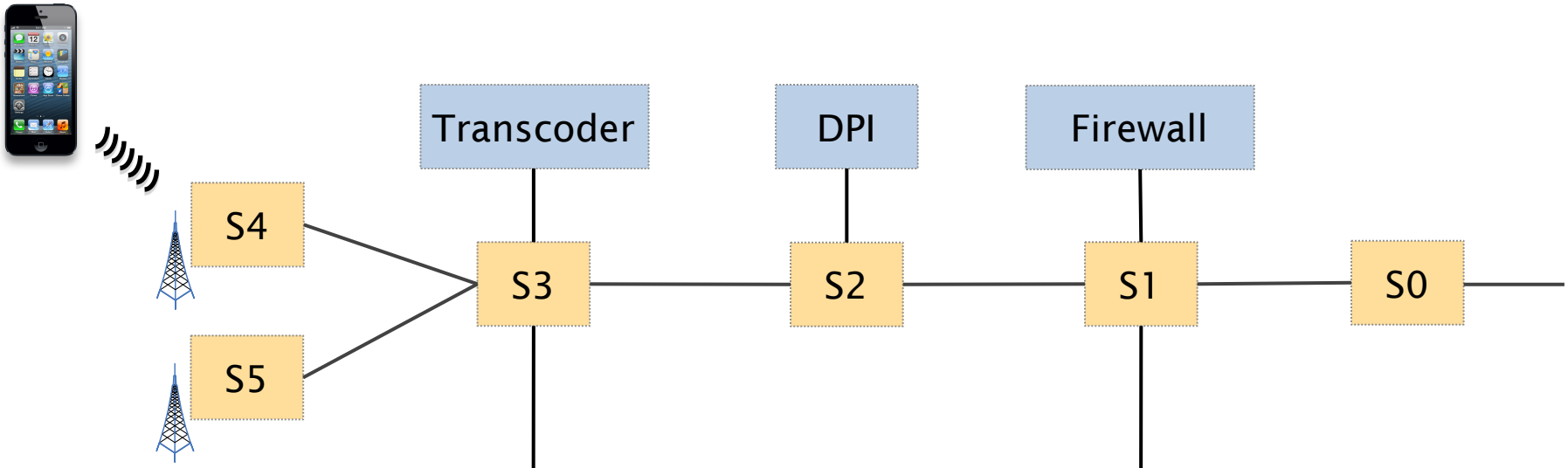

Match	Action
tag1	Forward to Transcoder

Match	Action
tag1	Forward to Firewall

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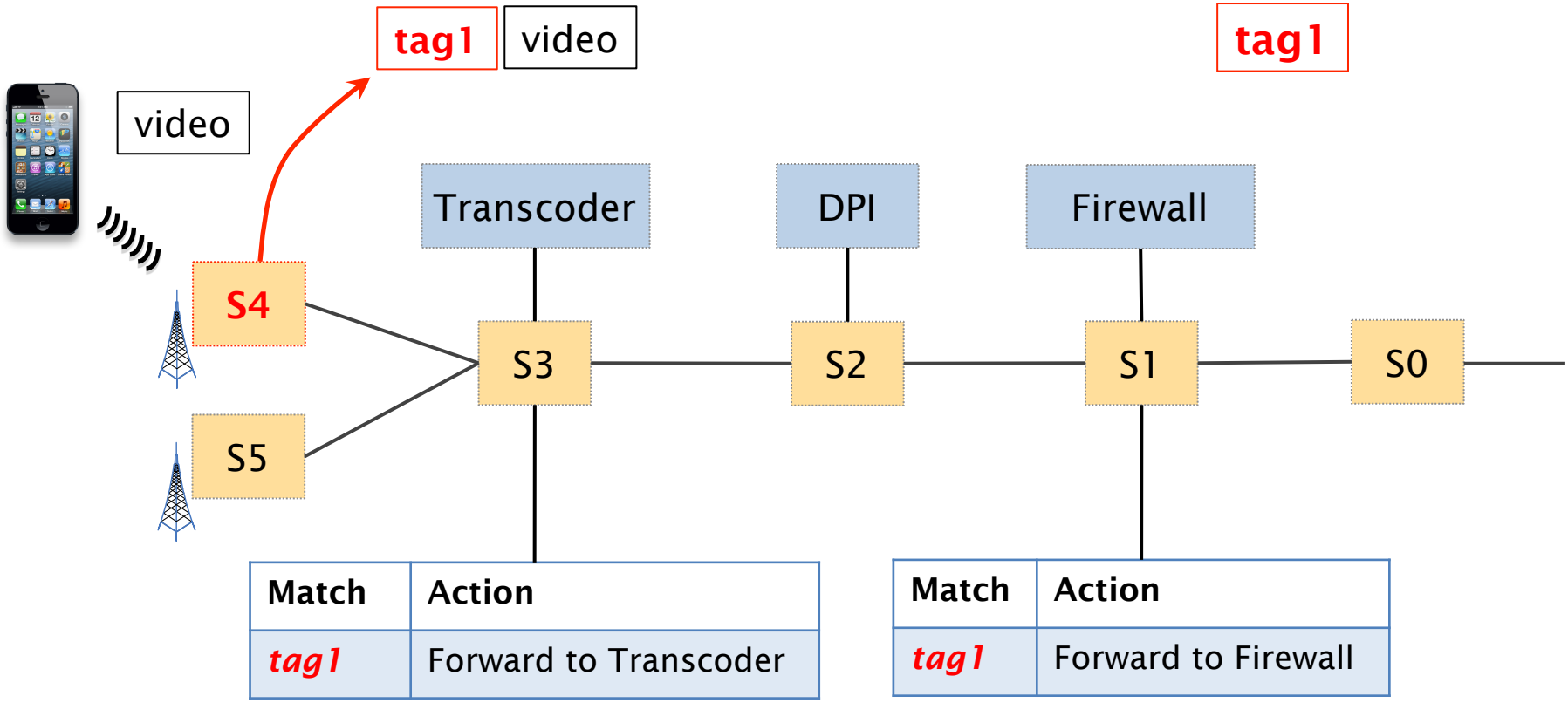

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Match	Action
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Video Traffic + Gold Membership = **Transcoder || Firewall**

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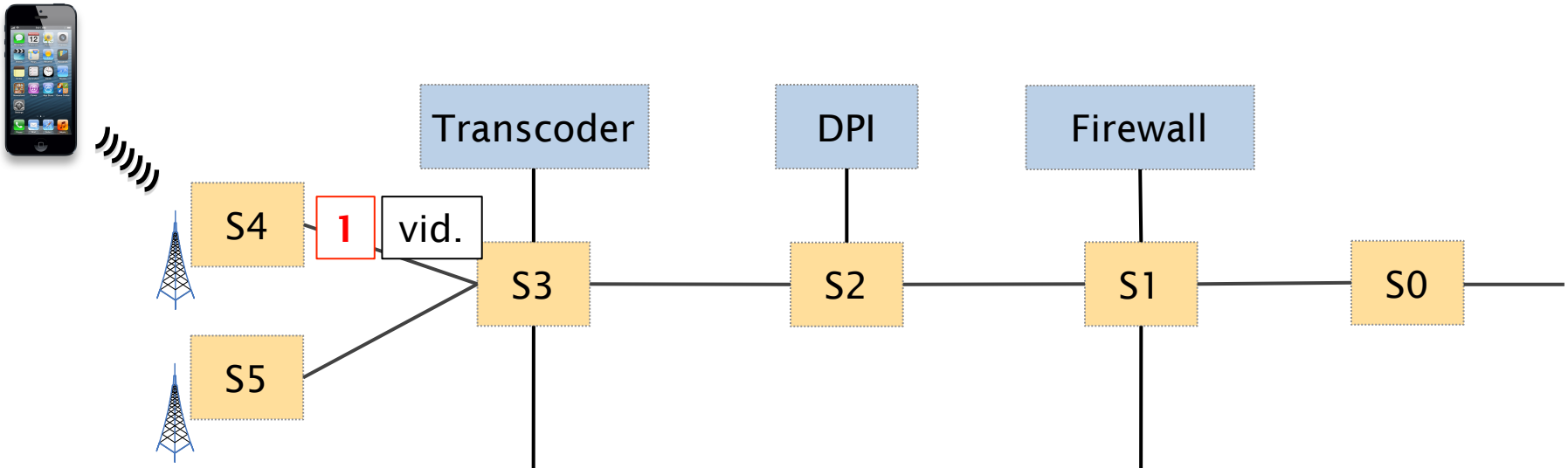

Match	Action
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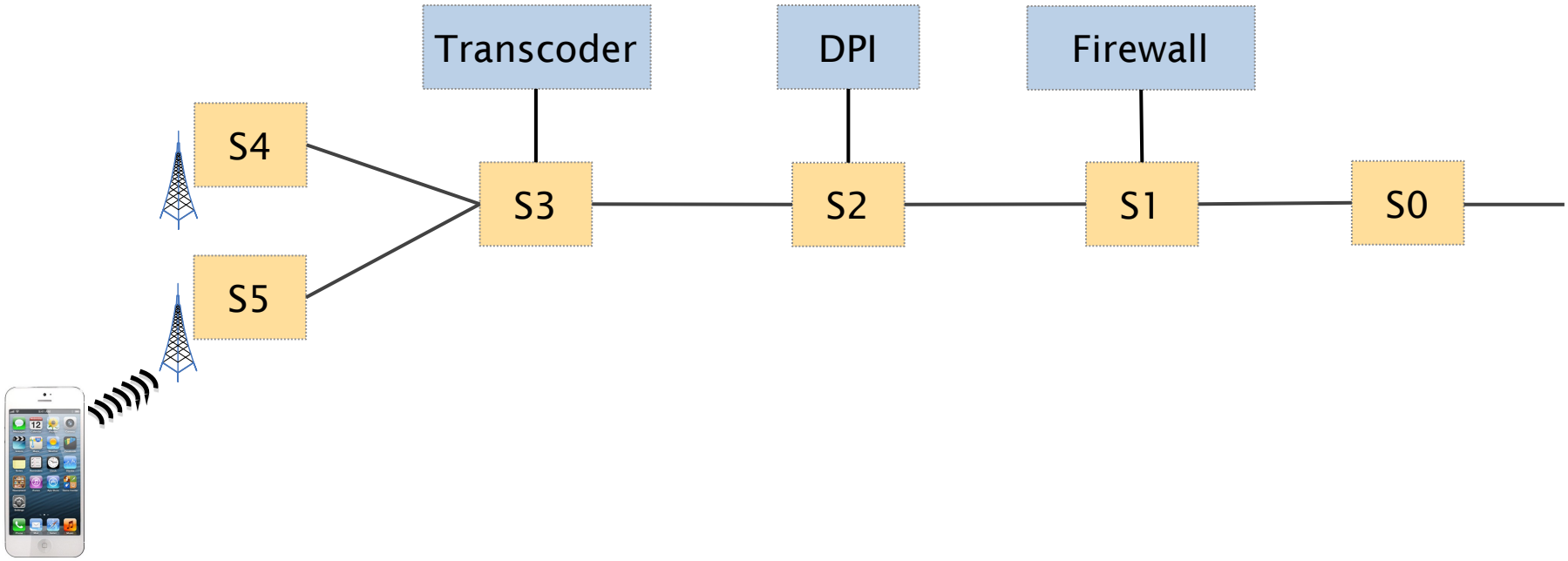
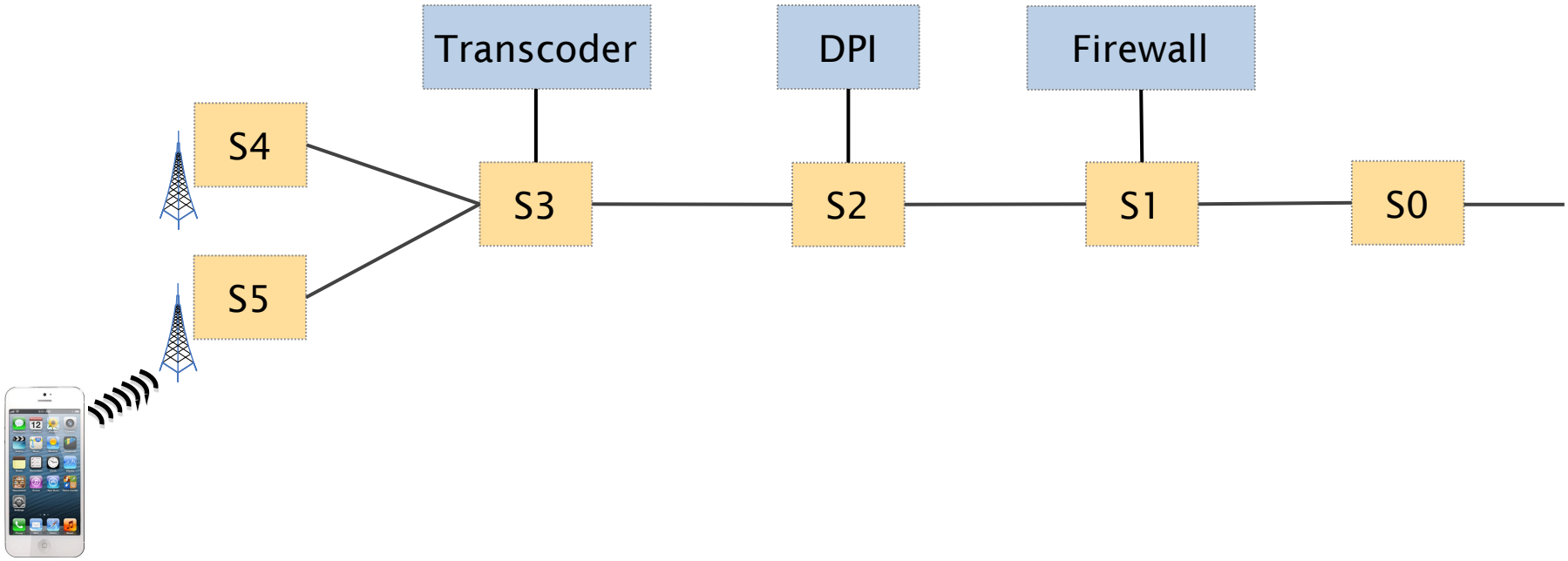
Match	Action
tag1	Forward to Firewall

Web Traffic + Feature Phone = DPI || Firewall



Web Traffic + Feature Phone = DPI || Firewall

tag2



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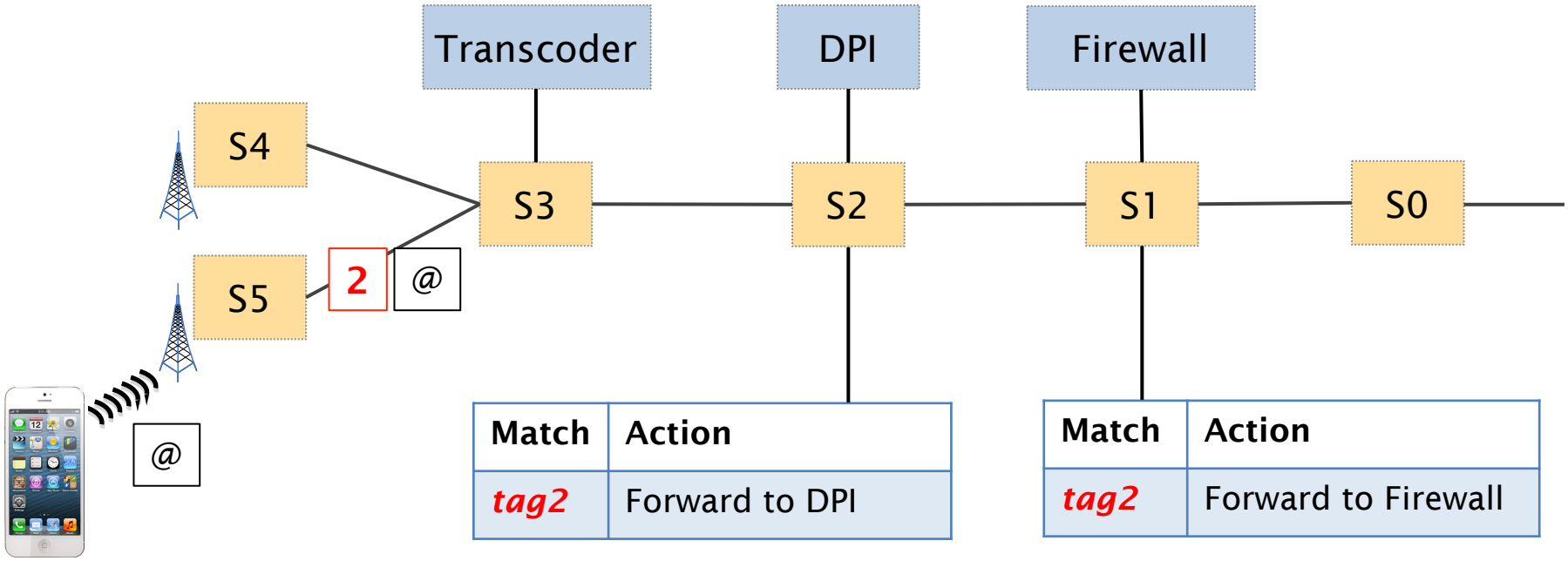


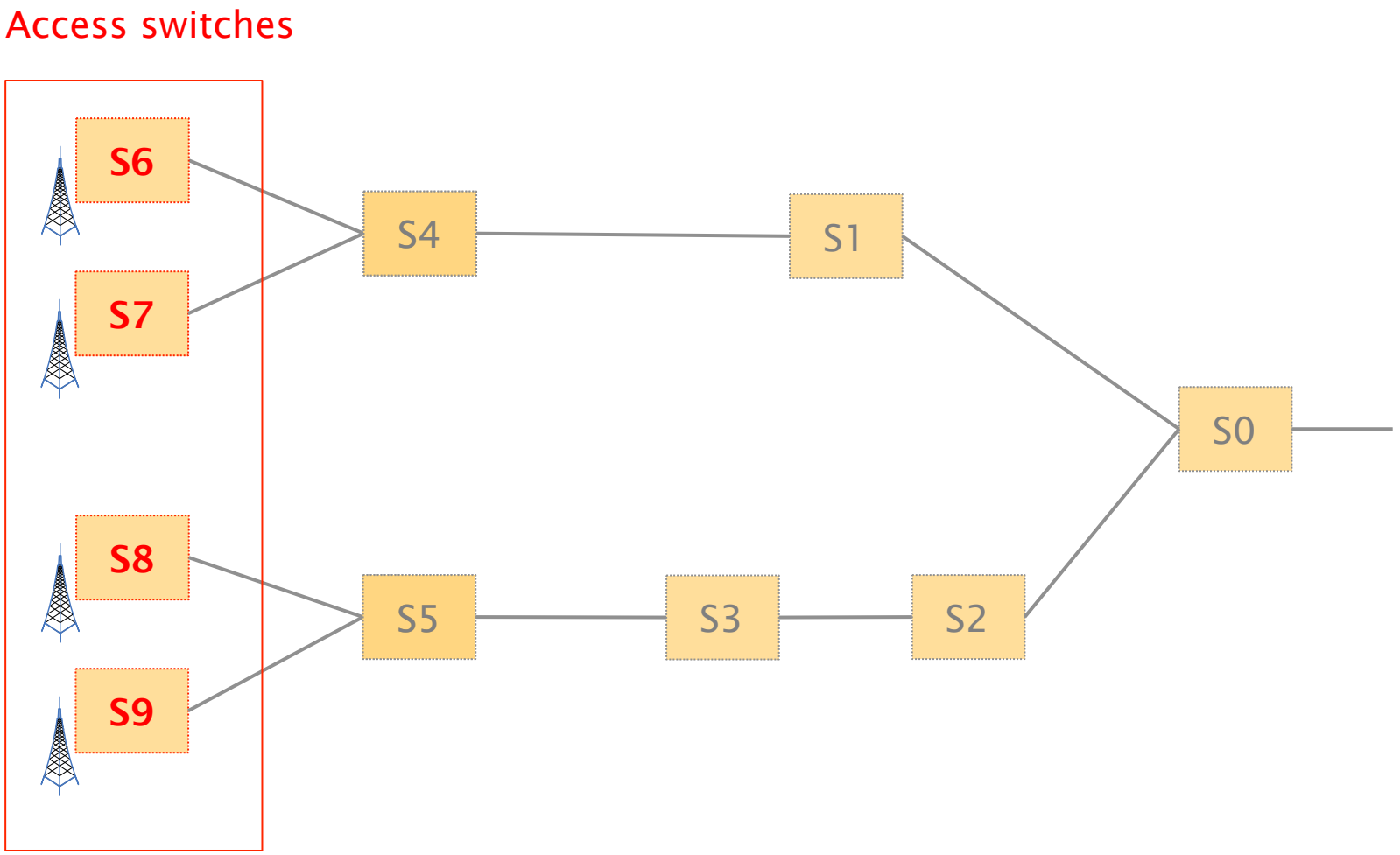
Match	Action
tag2	Forward to DPI

Match	Action
tag2	Forward to Firewall

CellSDN tags are composed of three parts:

- Policy
- **Location**
- User Equipment Identifier

In CellSDN, each base station is associated with an IP prefix



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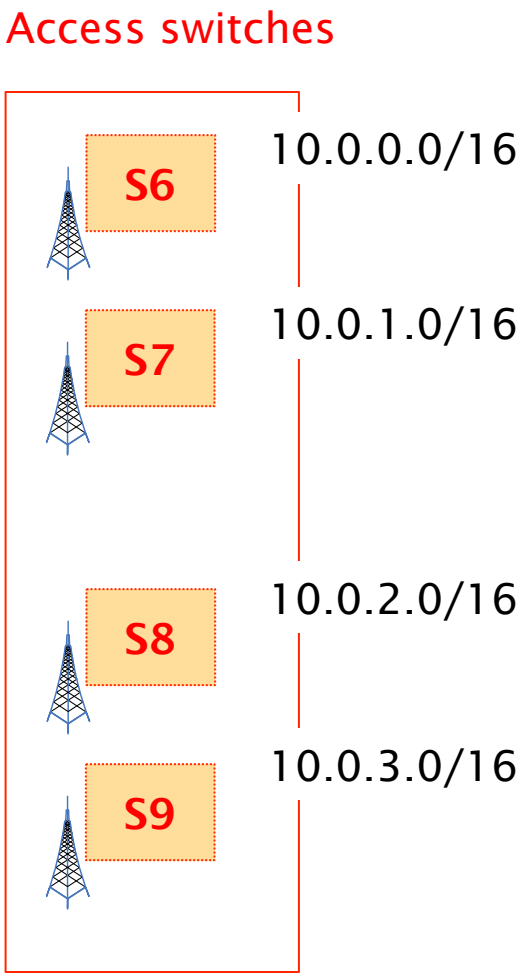
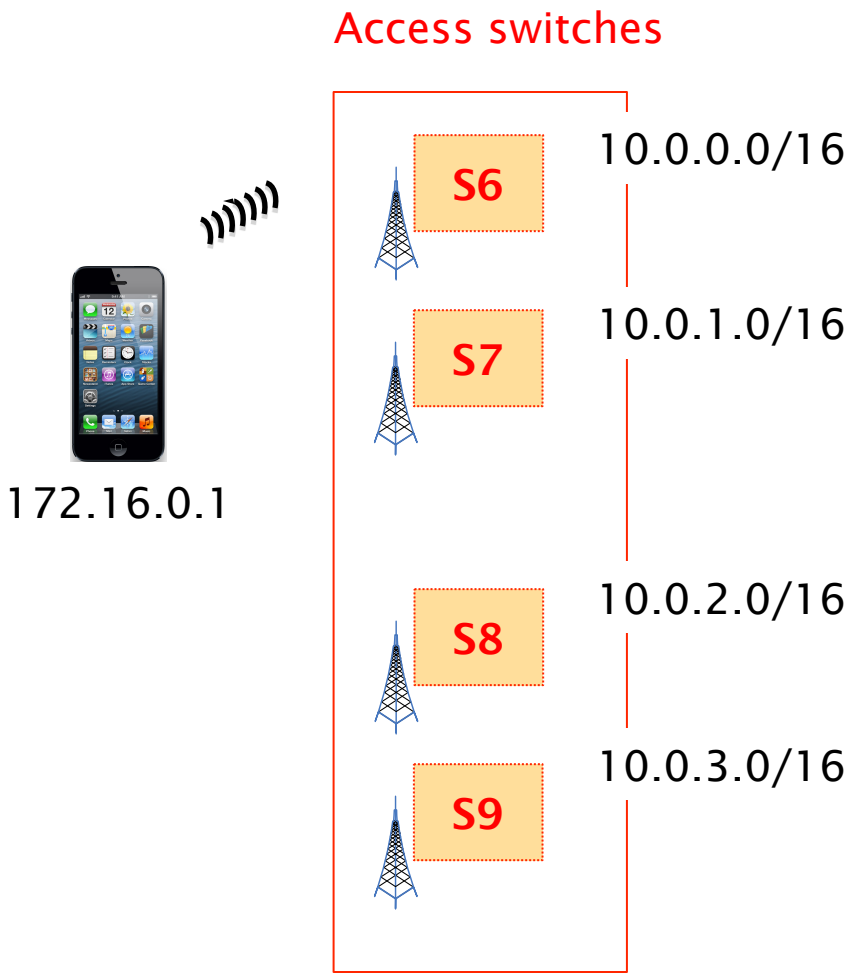
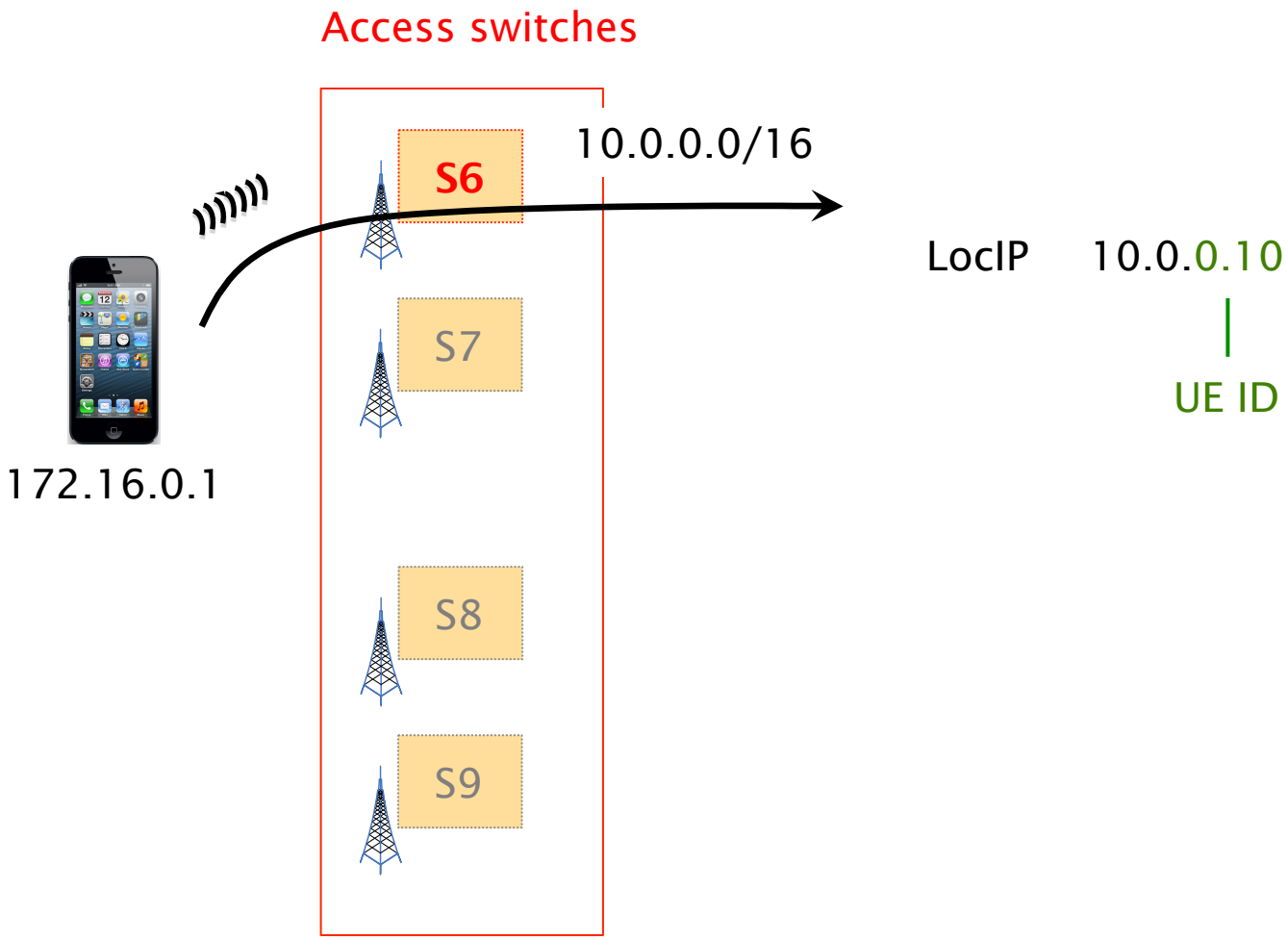


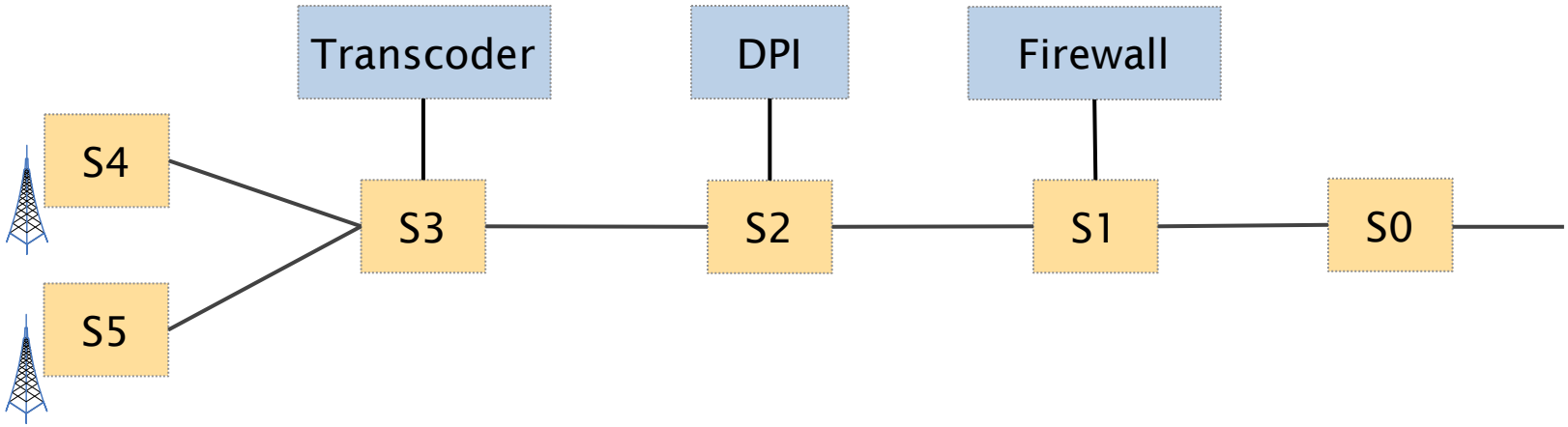
User Equipment receive a unique IP address



Access switches rewrite the UE IP into a location-dependent address



CellSDN can route based on Base Station prefixes



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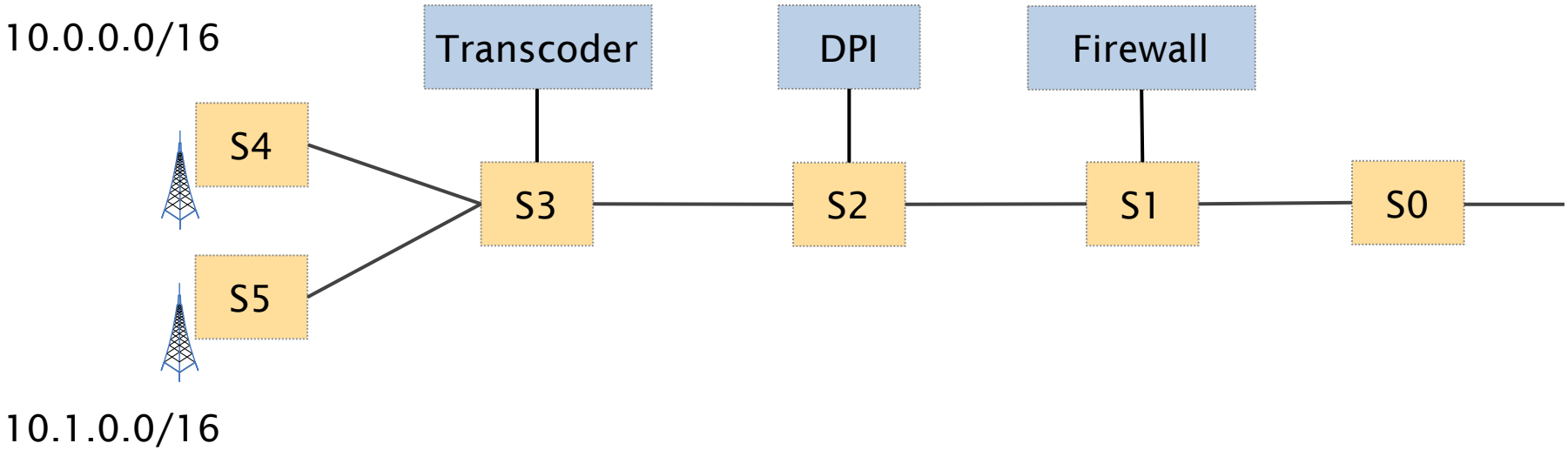

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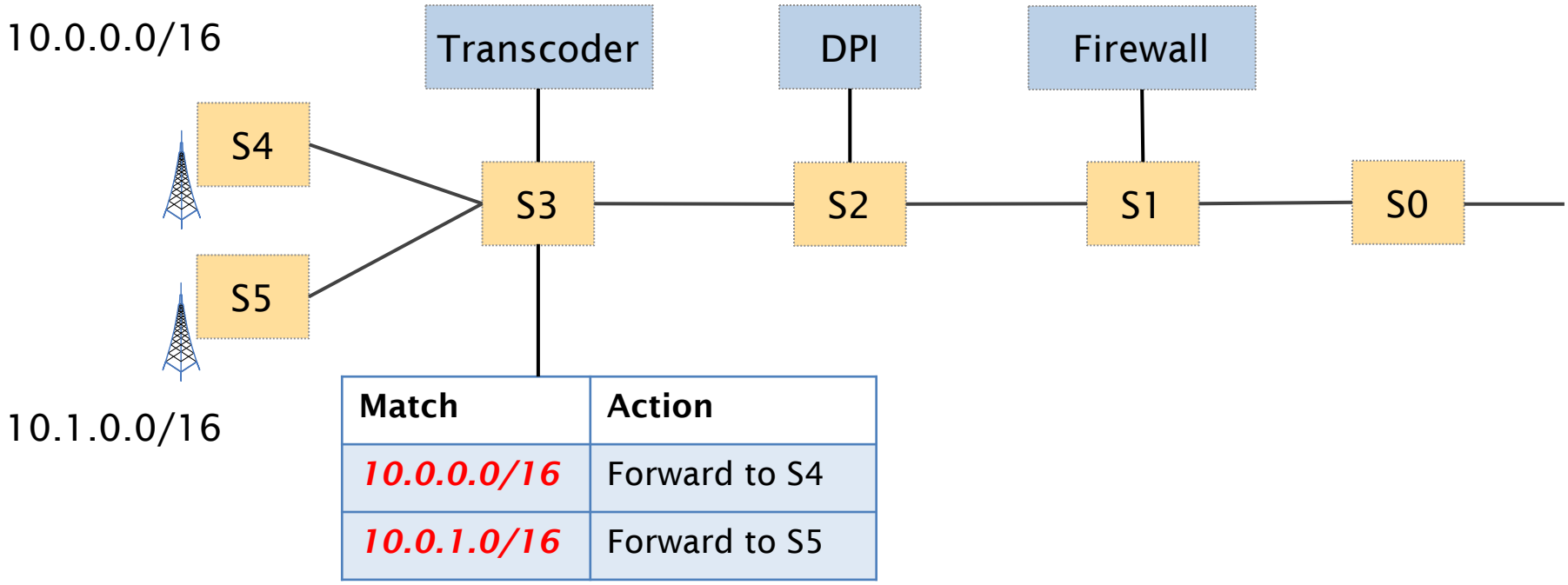
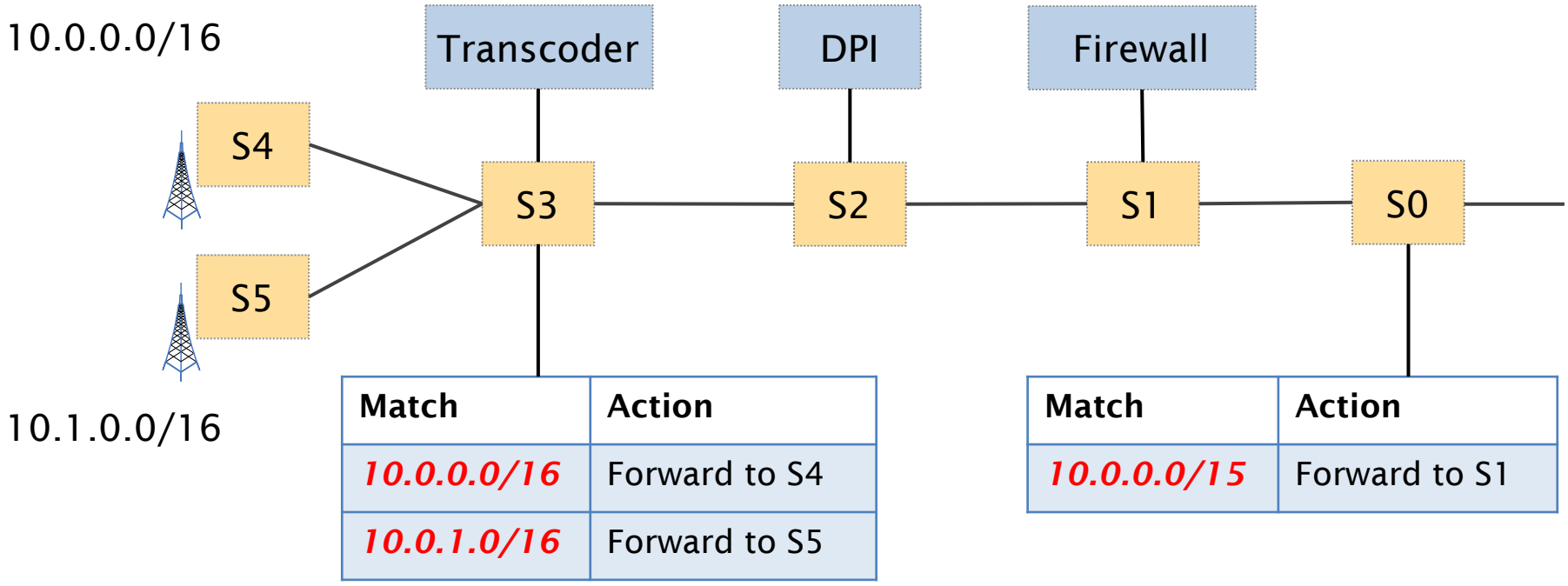


Match	Action
10.0.0.0/16	Forward to S4
10.0.1.0/16	Forward to S5

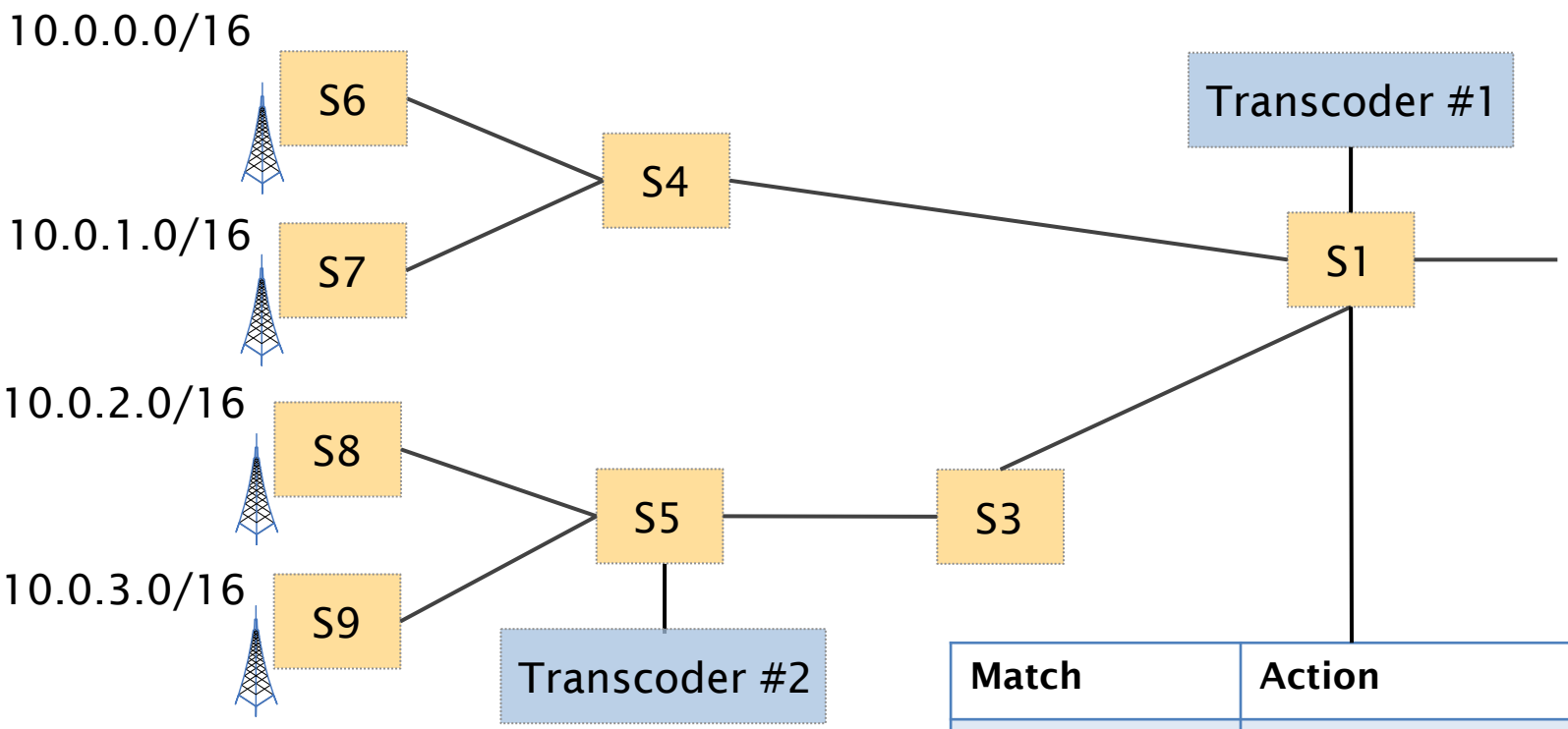
CellSDN automatically aggregates adjacent prefixes



Match	Action
10.0.0.0/16	Forward to S4
10.0.1.0/16	Forward to S5

Match	Action
10.0.0.0/15	Forward to S1

CellSDN can selectively match on tag and BS ID for load-balancing

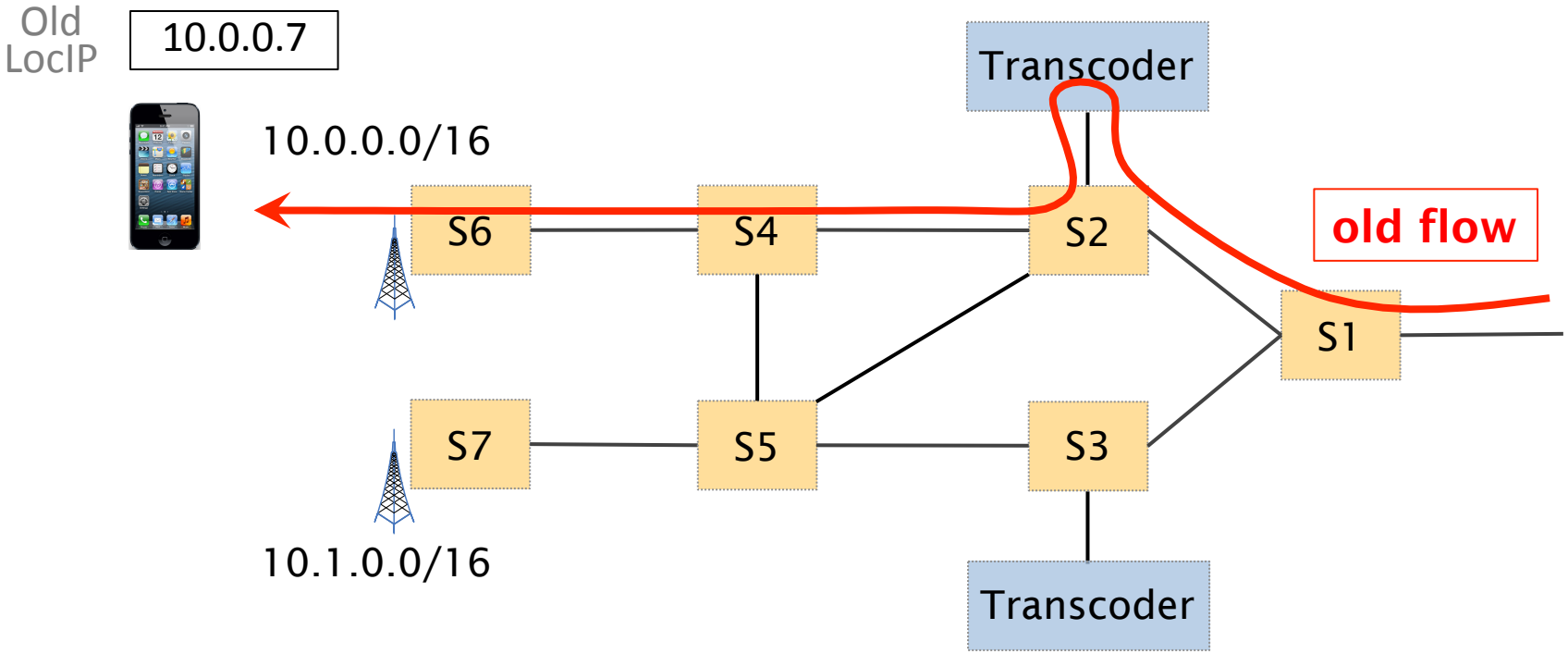


Match	Action
tag1 & 10.0.0.0/15	Forward to Transcoder #1
10.1.0.0/15	Forward to S3

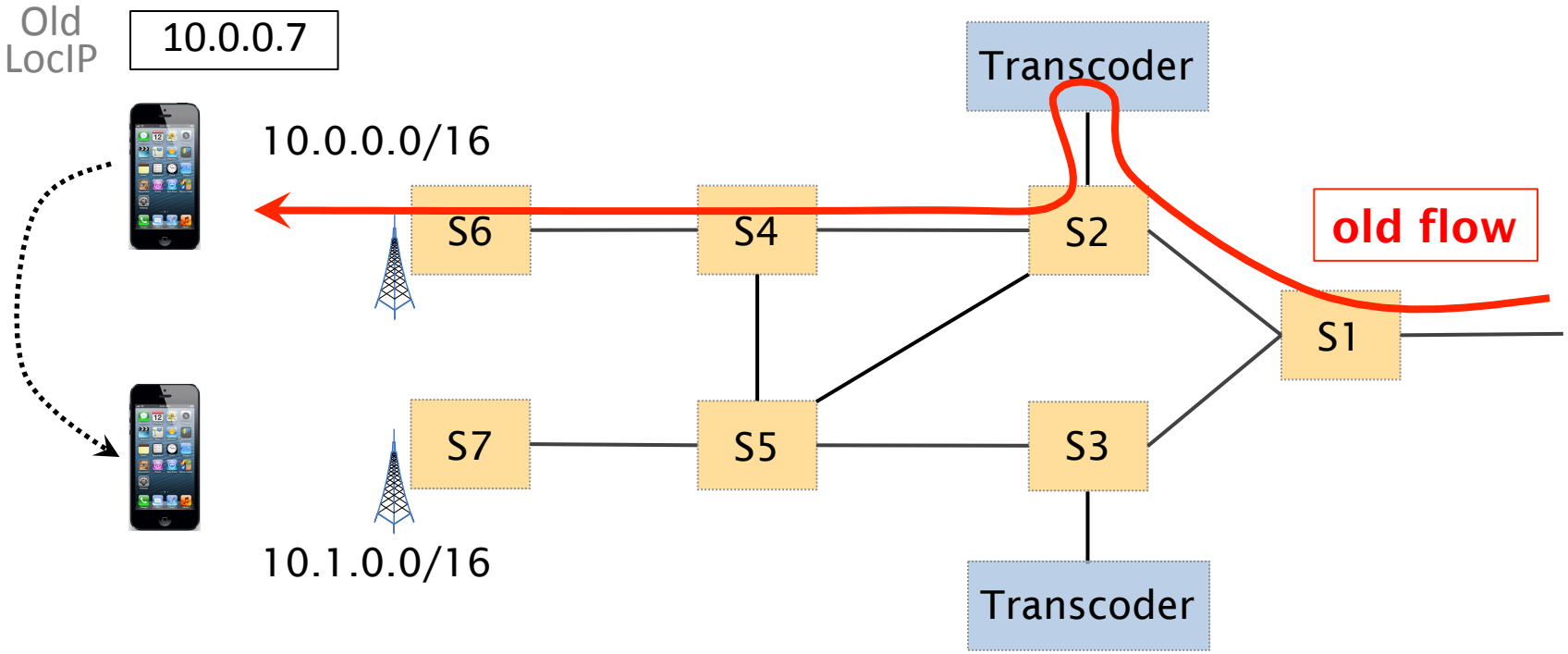
CellSDN tags are composed of three parts:

- Policy
- Location
- **User Equipment Identifier**

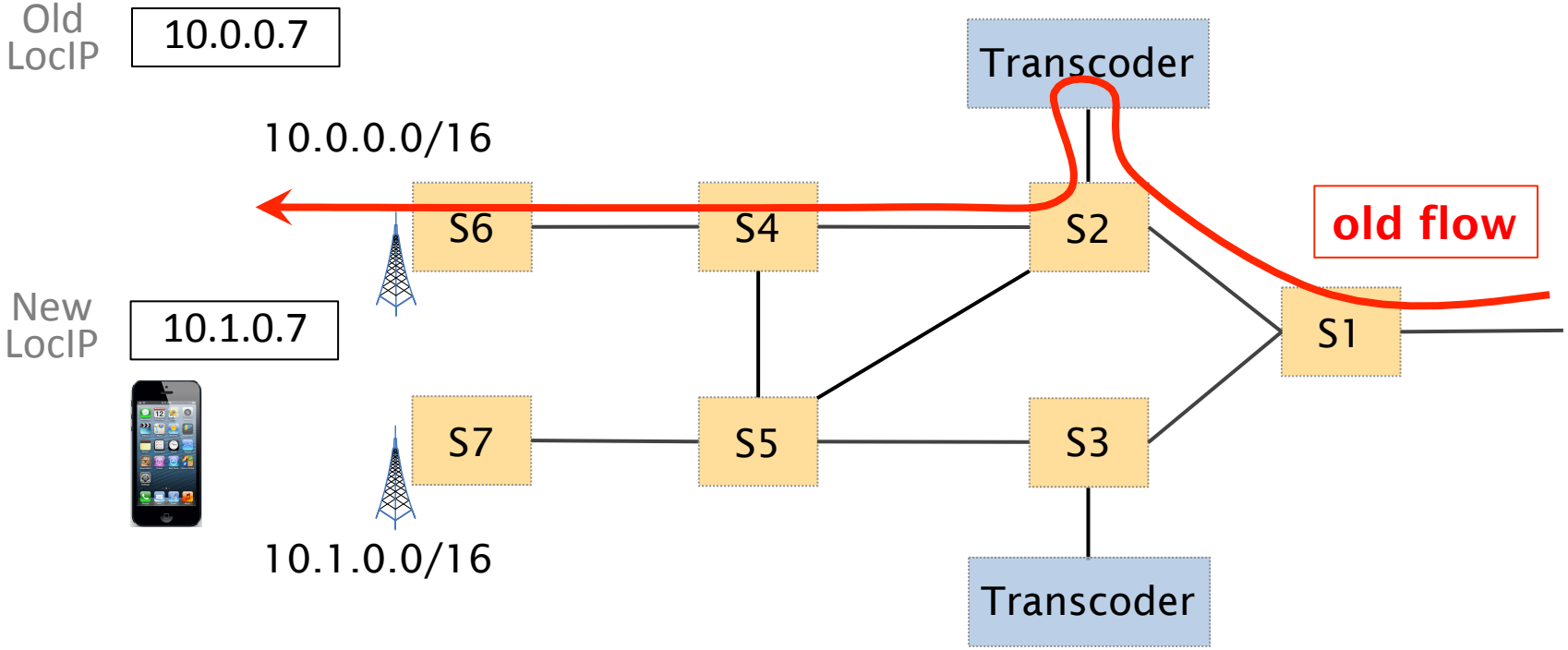
CellSDN UE tag enables mobility



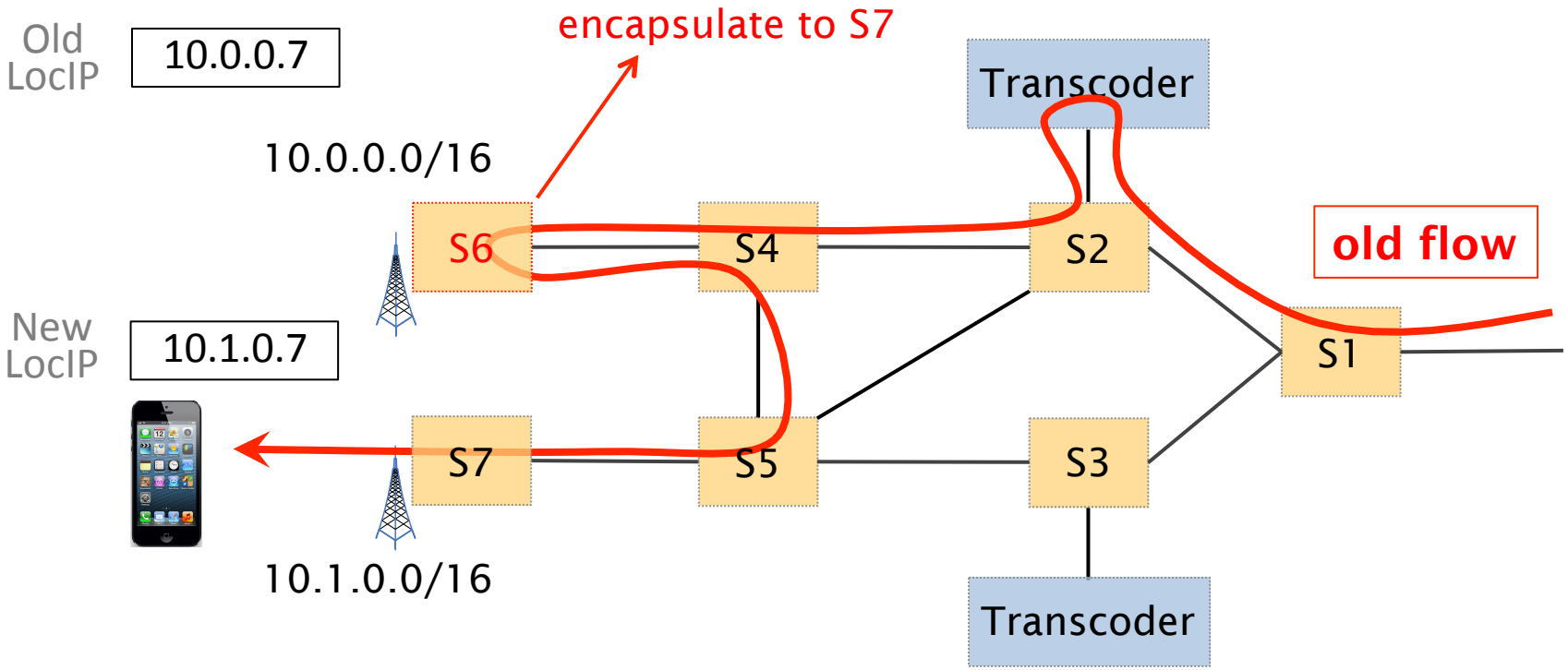
When an user moves, she receives a new LocIP



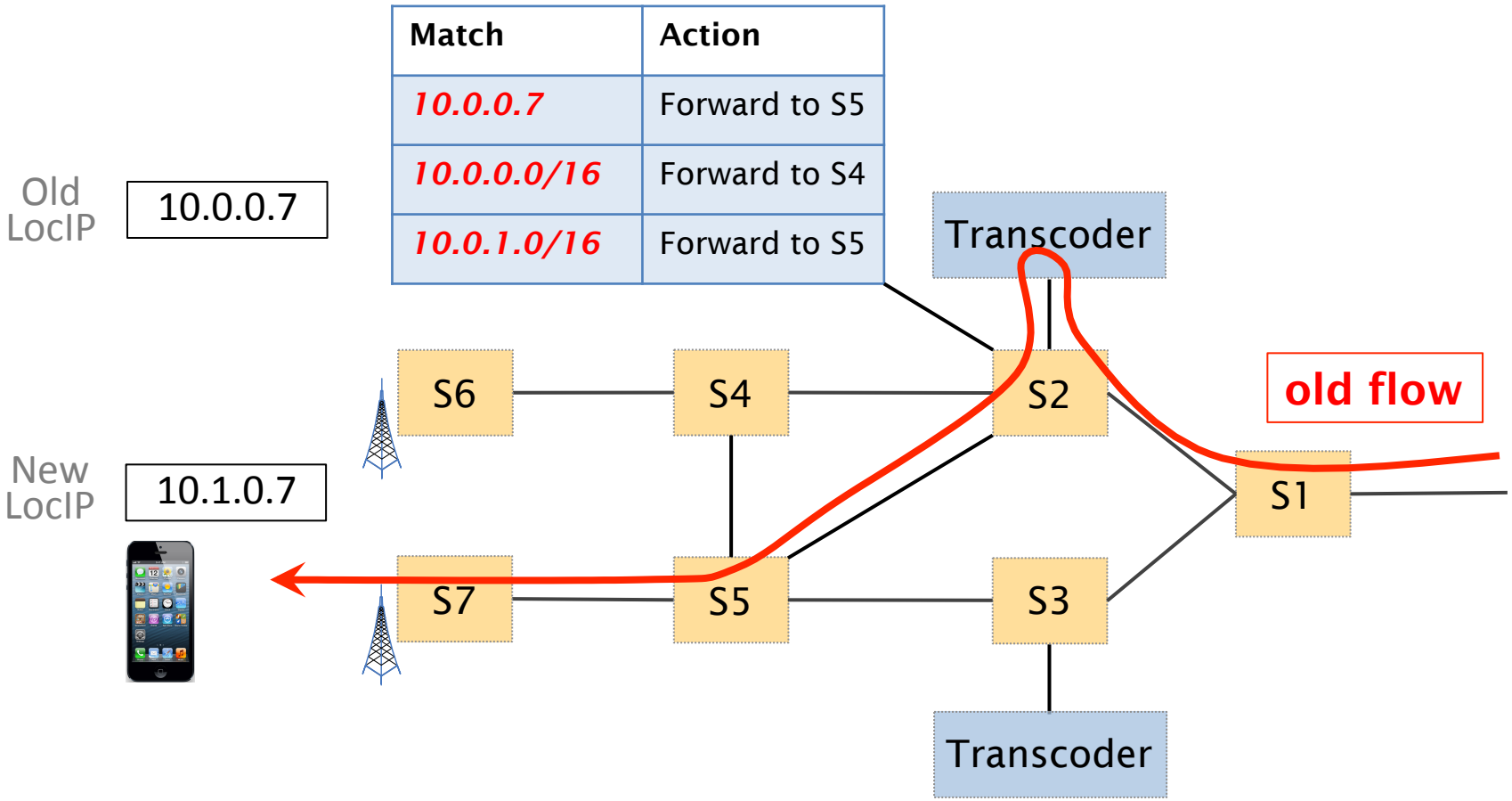
When an user moves, she receives a new LocIP



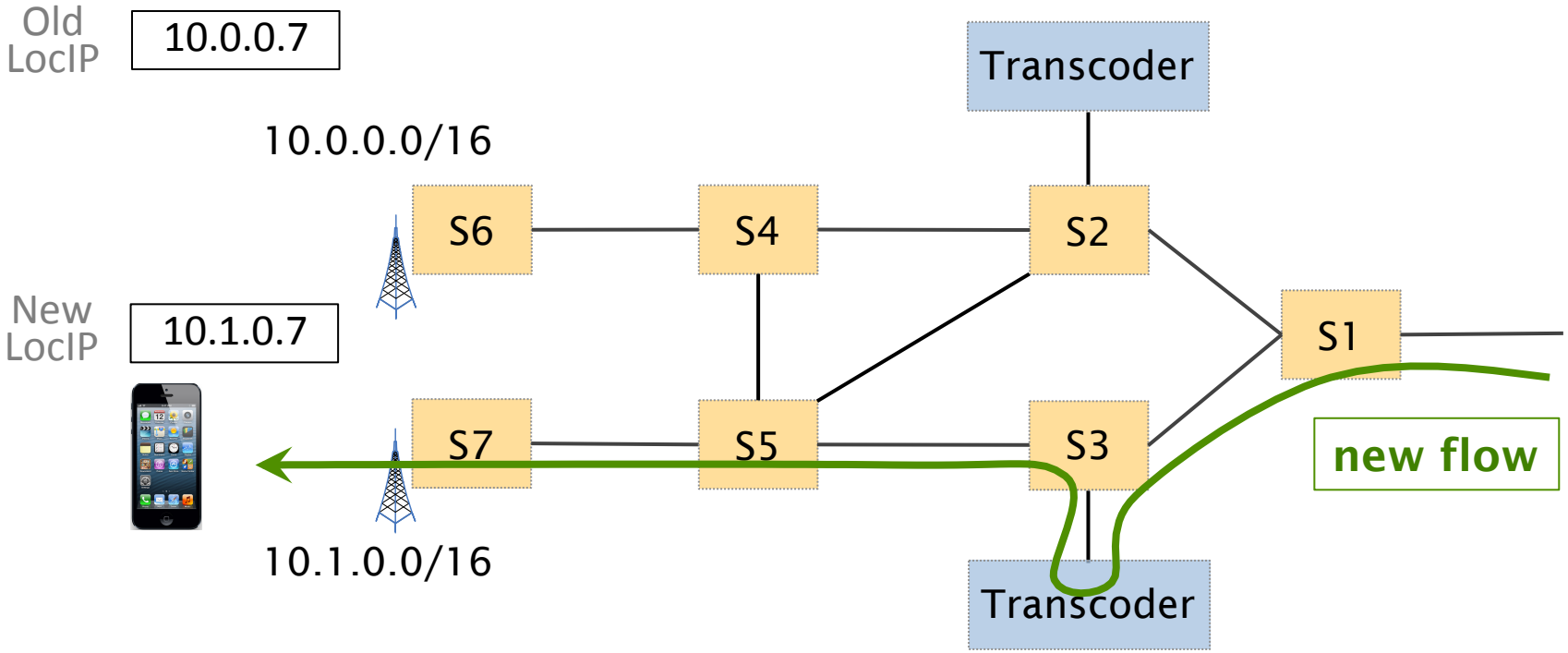
Old flows reach the previous base station, ensuring policy consistency



To avoid triangle routing, CellSDN can install shortcut path after the last MB



New flows automatically flow along new policy paths



CellSDN tags are composed of three parts:

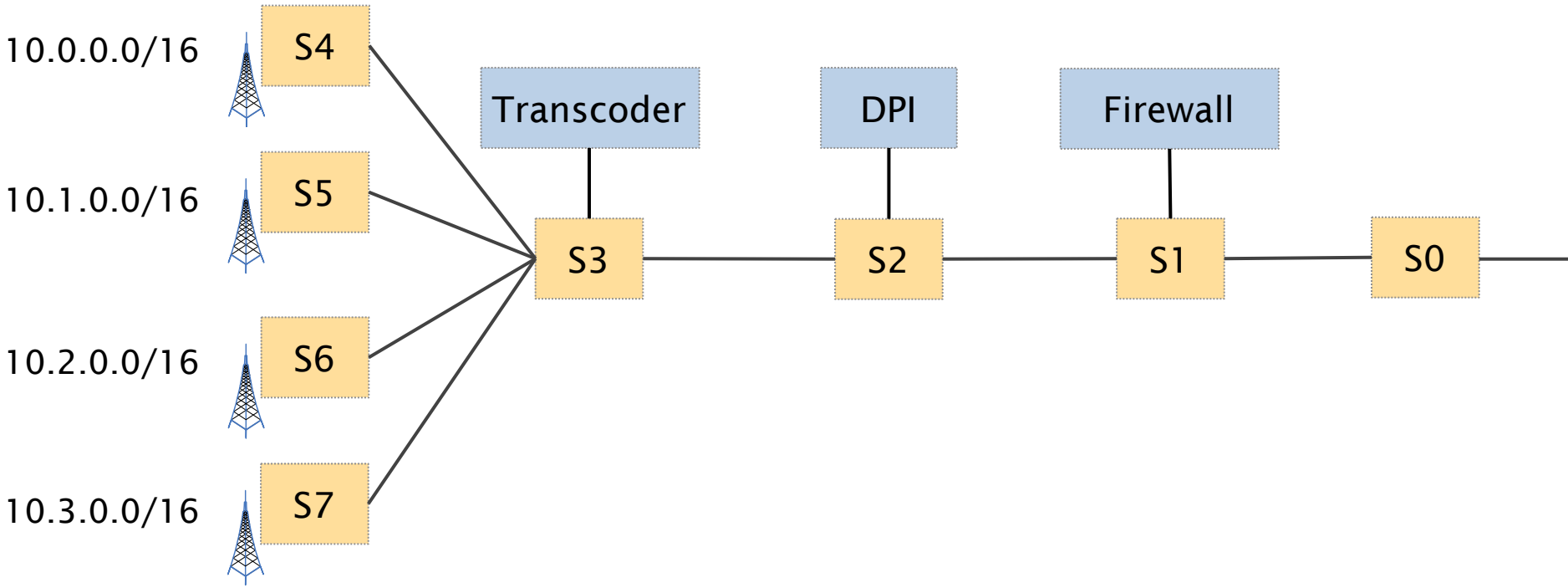
- Policy
- Location
- User Equipment Identifier

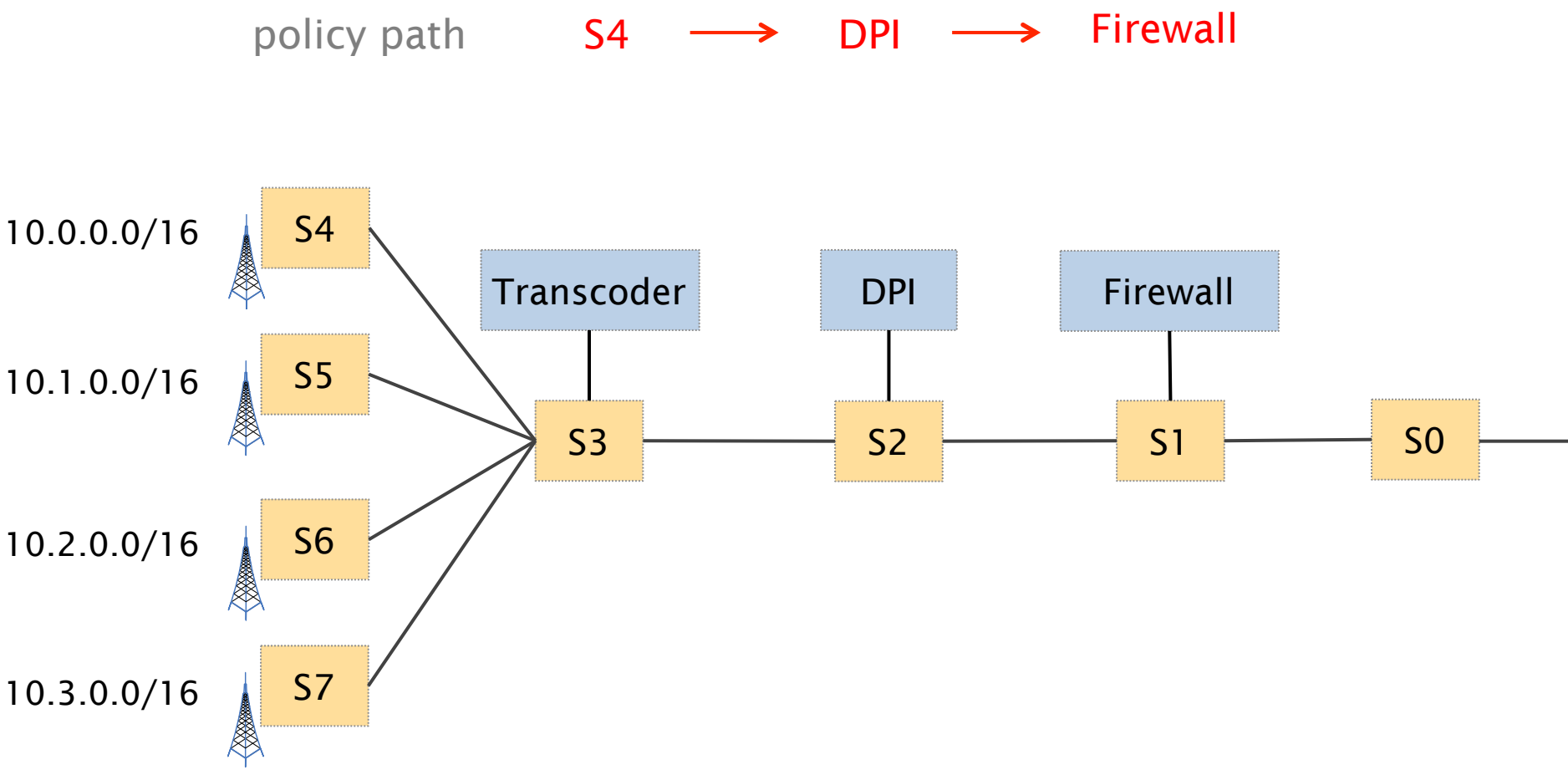
How does CellSDN compute these tags?

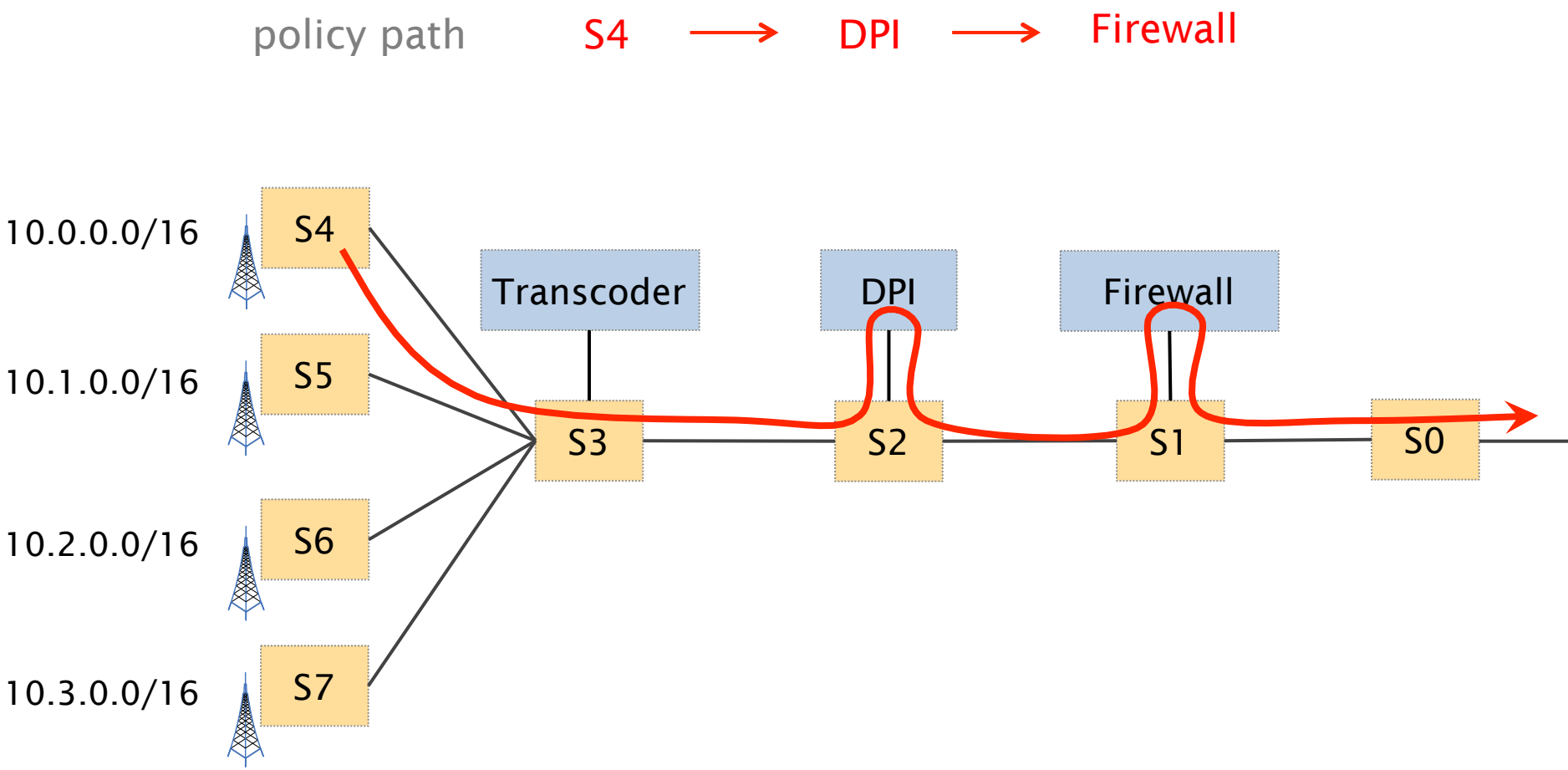
CellSDN minimizes the forwarding tables size by reusing tags

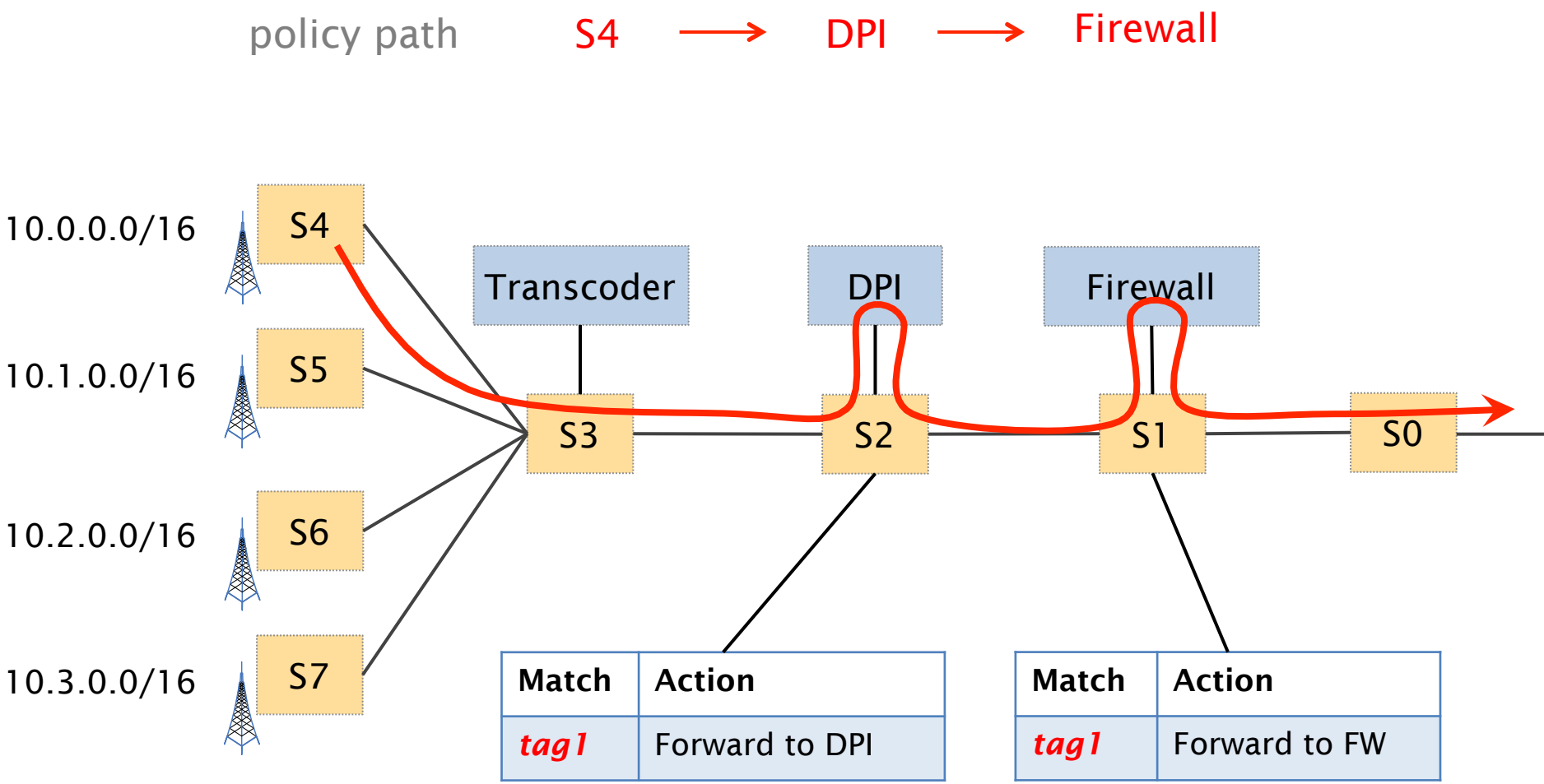
Given a service policy-path,

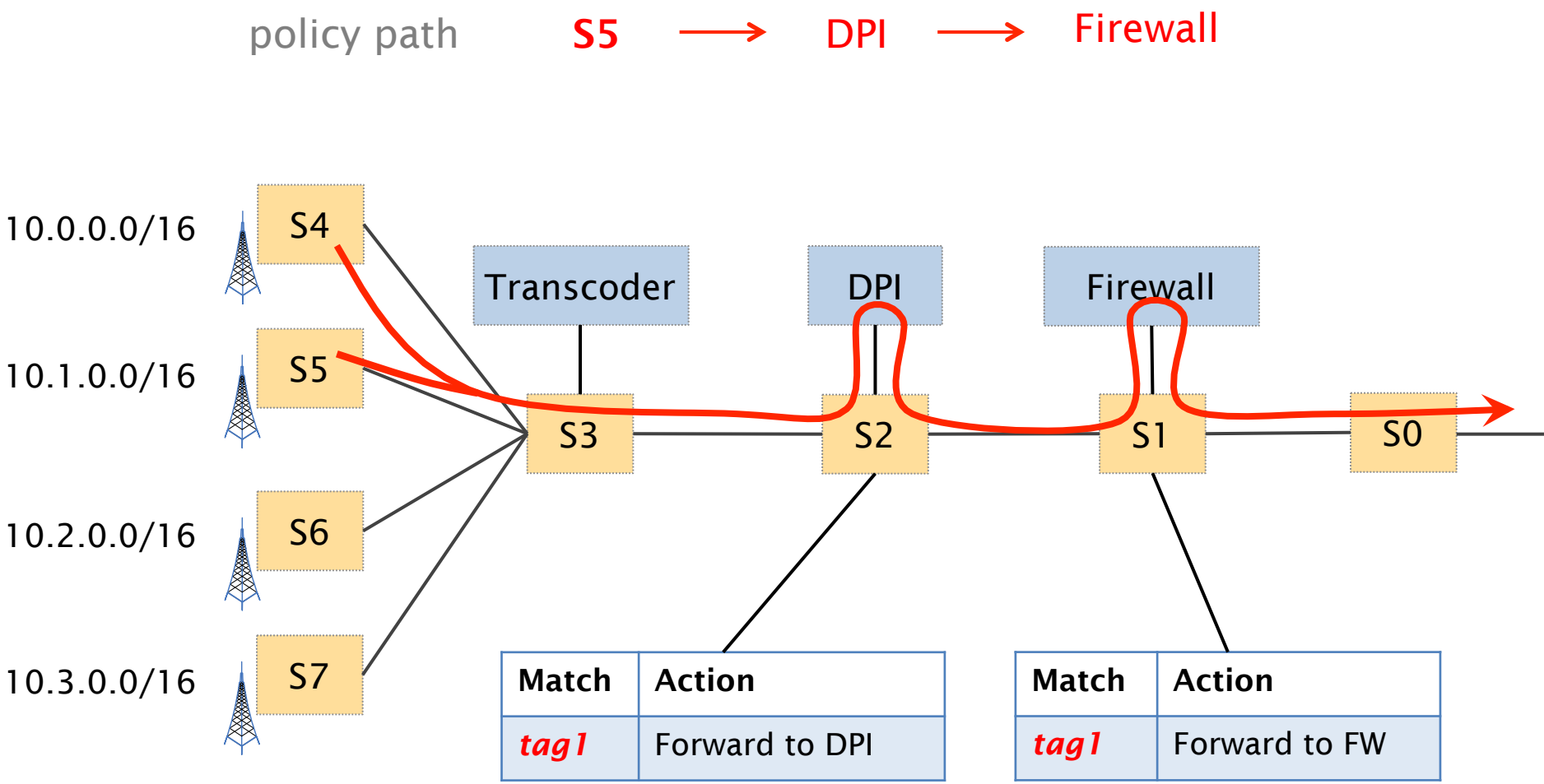
1. Compute the actual path *P* used in the network
2. For each candidate tag *t* used on the path *P*,
   Compute the # of new rules needed if *t* is used
3. Select the candidate tag minimizing the # of new rules,
   Create new tag if none available
4. Install the forwarding entries in the network

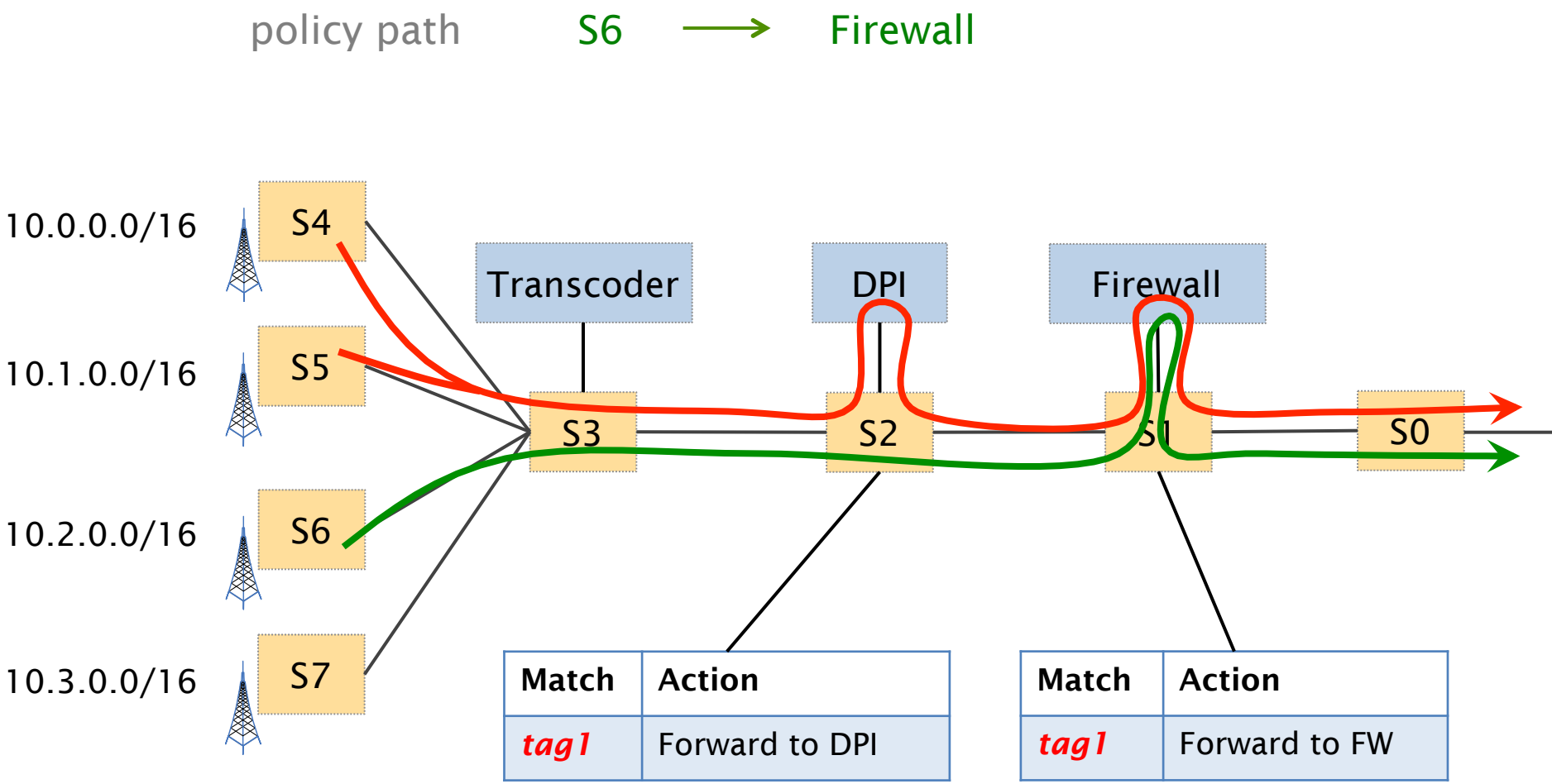

10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
DPI
Firewall
S3
S2
S1
S0


policy path
S4
DPI
Firewall
10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
DPI
Firewall
S3
S2
S1
S0

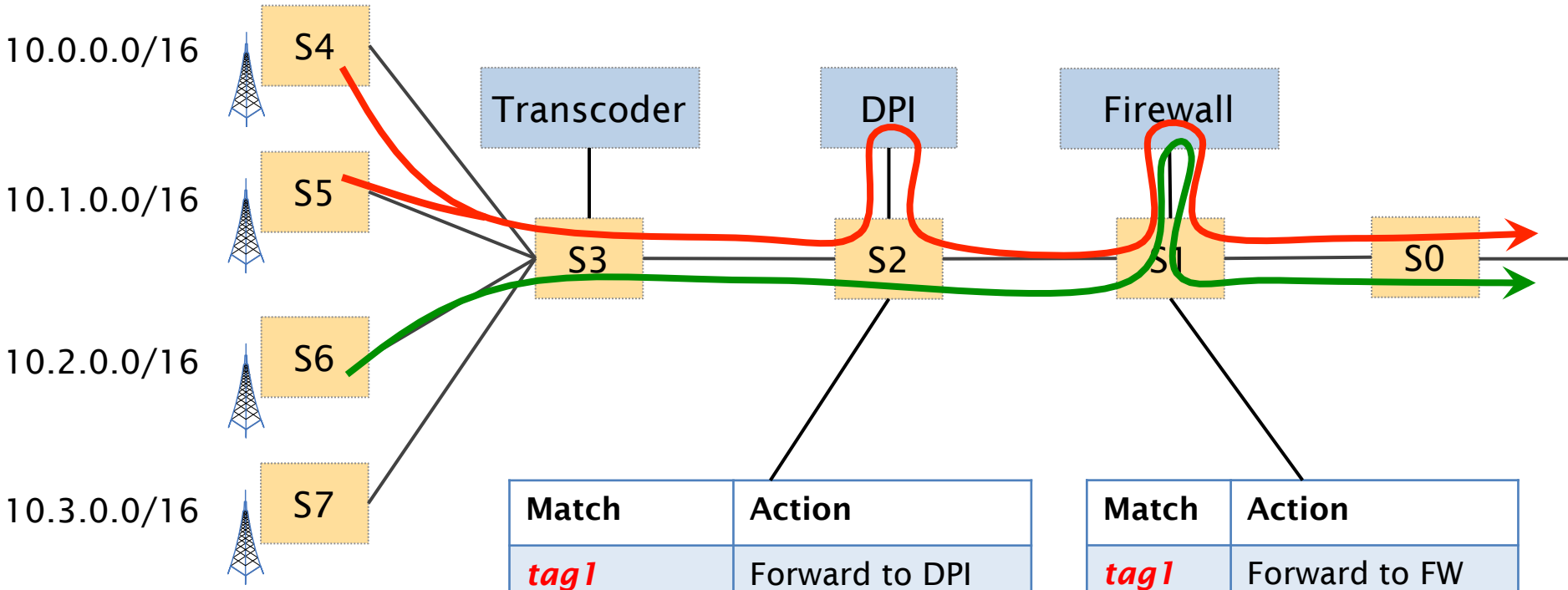

policy path
S4
DPI
Firewall
10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
S3
DPI
S2
Firewall
S1
S0


policy path
S4
DPI
Firewall
10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
DPI
Firewall
S3
S2
S1
S0
Match
Action
tag1
Forward to DPI
Match
Action
tag1
Forward to FW


policy path
S5
DPI
Firewall
10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
DPI
Firewall
S3
S2
S1
S0
Match
Action
tag1
Forward to DPI
Match
Action
tag1
Forward to FW


policy path
S6
Firewall
10.0.0.0/16
10.1.0.0/16
10.2.0.0/16
10.3.0.0/16
S4
S5
S6
S7
Transcoder
DPI
Firewall
S3
S2
S1
S0
Match
Action
tag1
Forward to DPI
Match
Action
tag1
Forward to FW

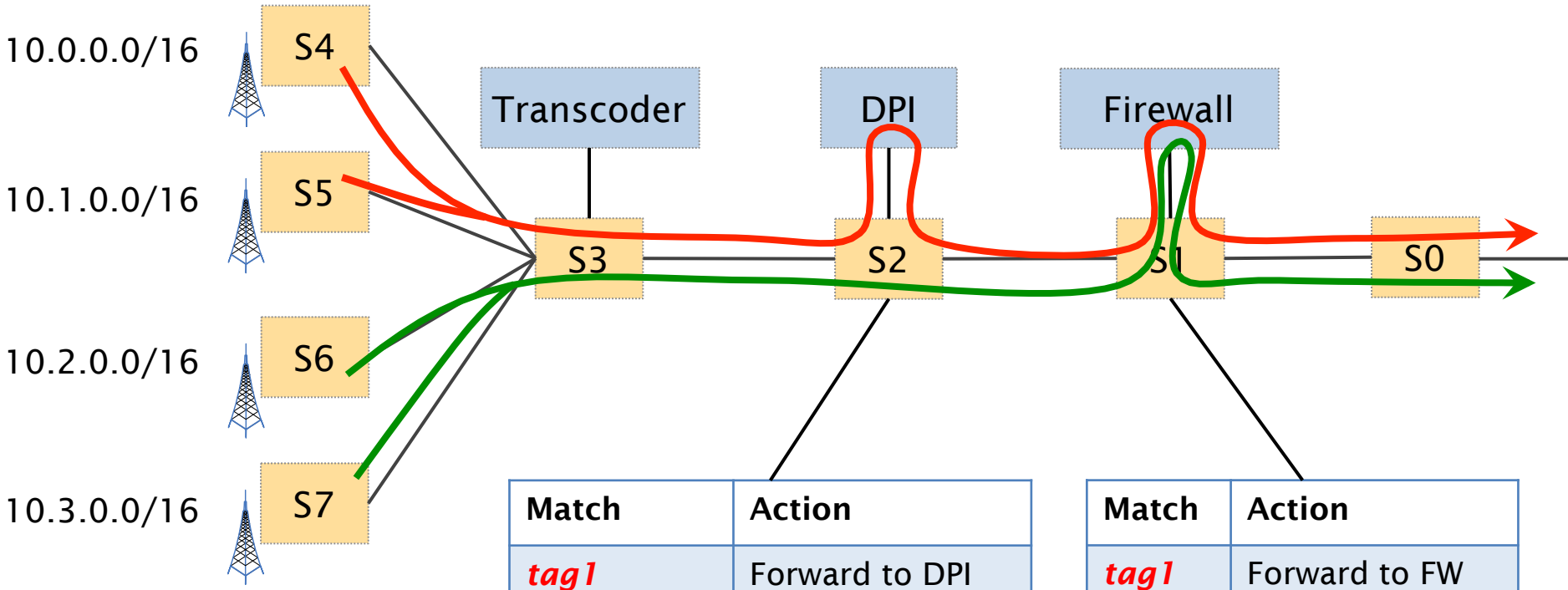
policy path S6 → Firewall



Match	Action
tag1	Forward to DPI
tag1, src: 10.2.0.0/16	Forward to S1

Match	Action
tag1	Forward to FW

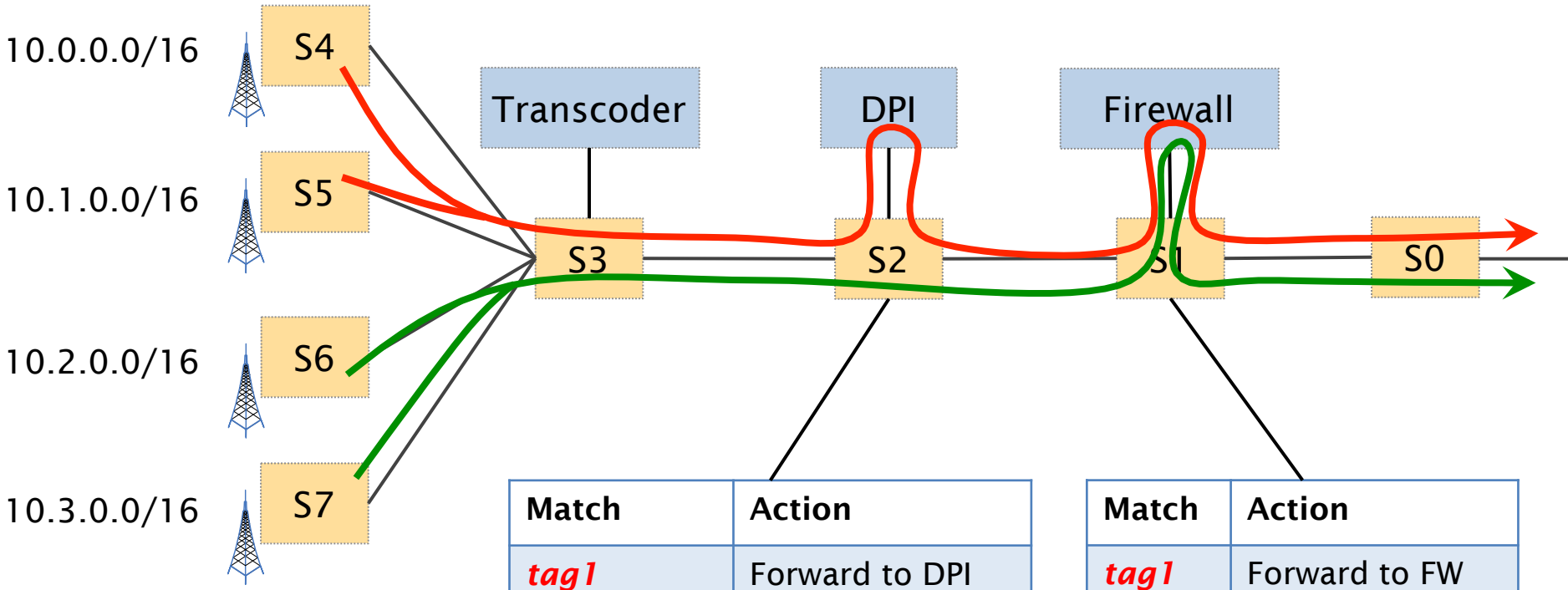
policy path **S7** → Firewall



Match	Action
tag1	Forward to DPI
tag1, src: 10.2.0.0/16	Forward to S1

Match	Action
tag1	Forward to FW

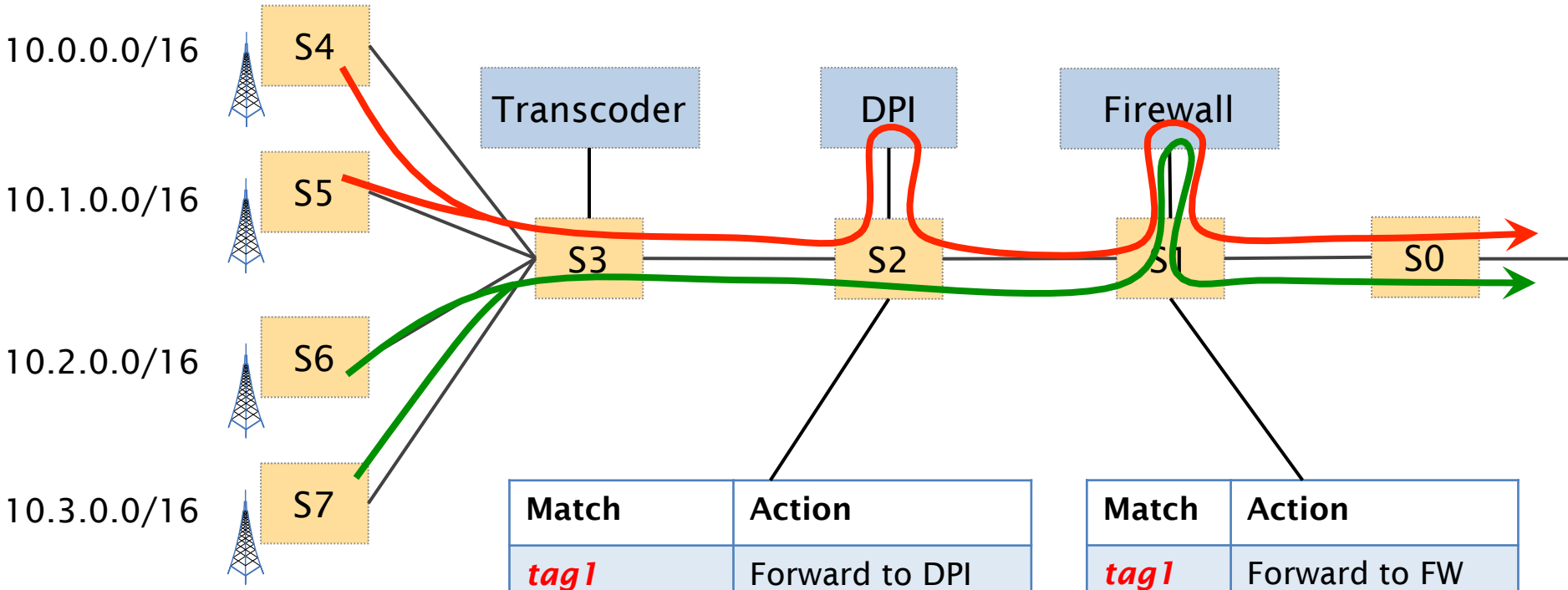
policy path **S7** → Firewall



Match	Action
tag1	Forward to DPI
tag1, src: 10.2.0.0/16	Forward to S1
tag1,src: 10.3.0.0/16	Forward to S1

Match	Action
tag1	Forward to FW

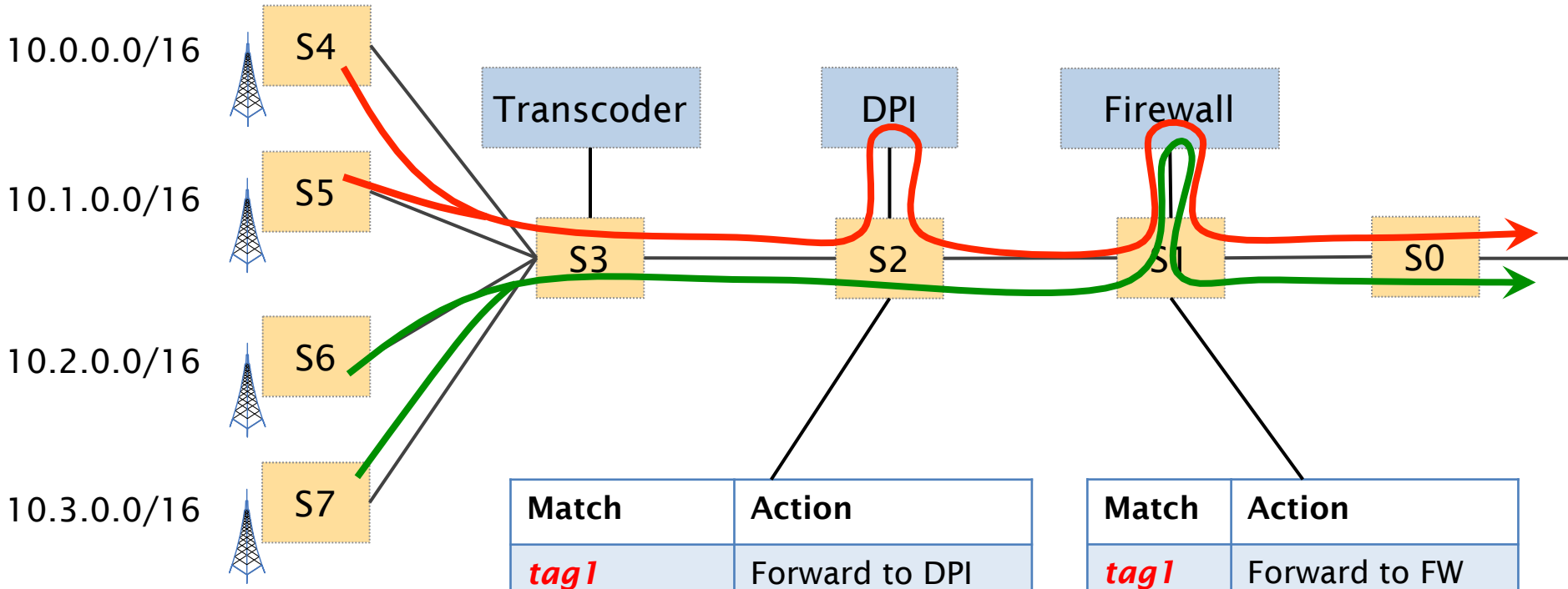
policy path **S7** → Firewall



Match	Action
tag1	Forward to DPI
tag1, src: 10.2.0.0/16	Forward to S1
tag1,src: 10.3.0.0/16	Forward to S1

Match	Action
tag1	Forward to FW

policy path **S7** → Firewall



Match	Action
tag1	Forward to DPI
tag1, src: 10.2.0.0/15	Forward to S1

Match	Action
tag1	Forward to FW

CellSDN dataplane can support a large number of service policies

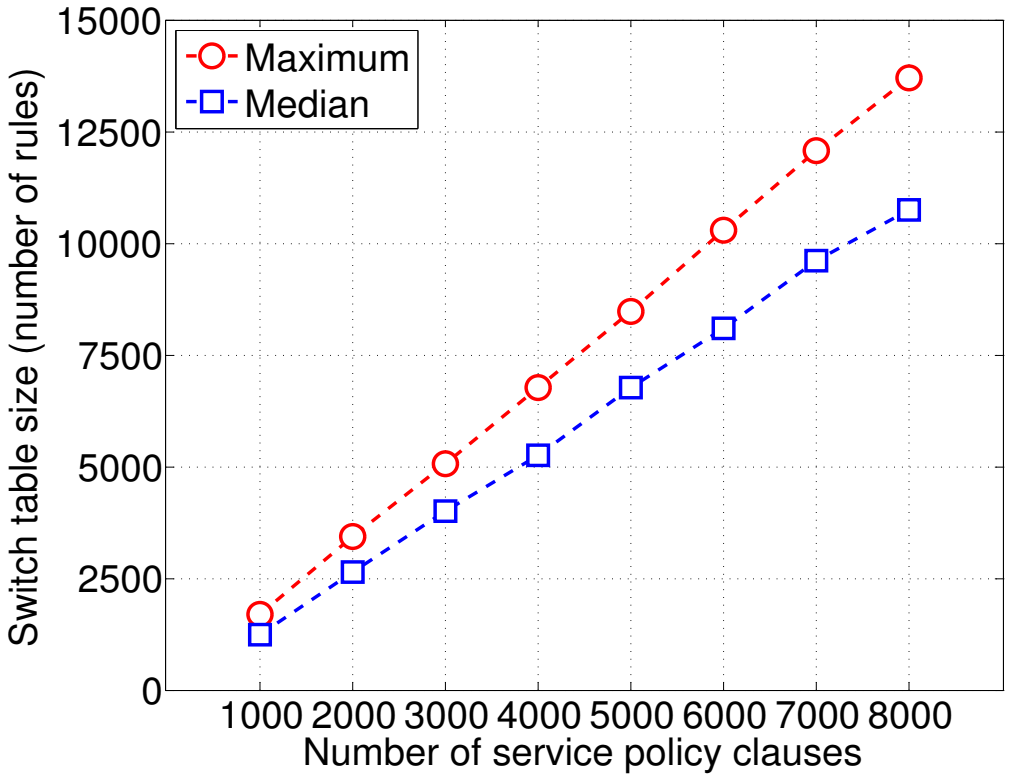
Simulation

- FatTree topology
- 128 switches && 1280 base stations
- 8 types of middleboxes
- 5 middleboxes long service policy

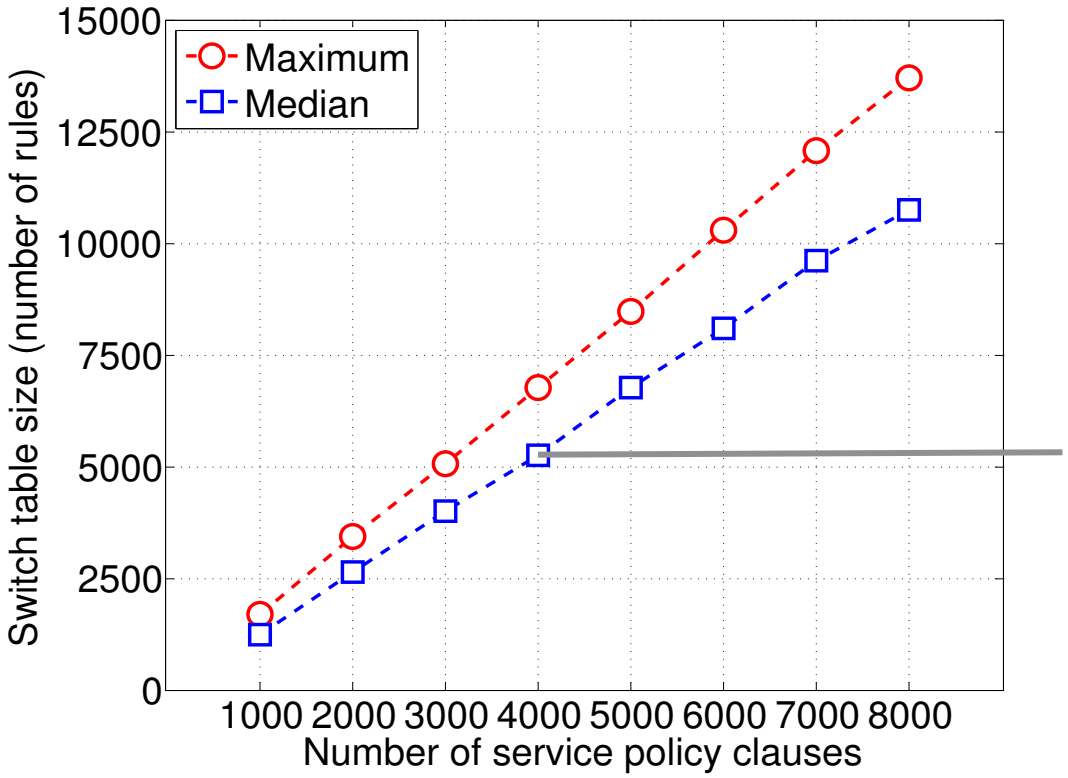
Evaluation

table size in function of the # of policies

Switches table size increase linearly wrt to the # of policy paths

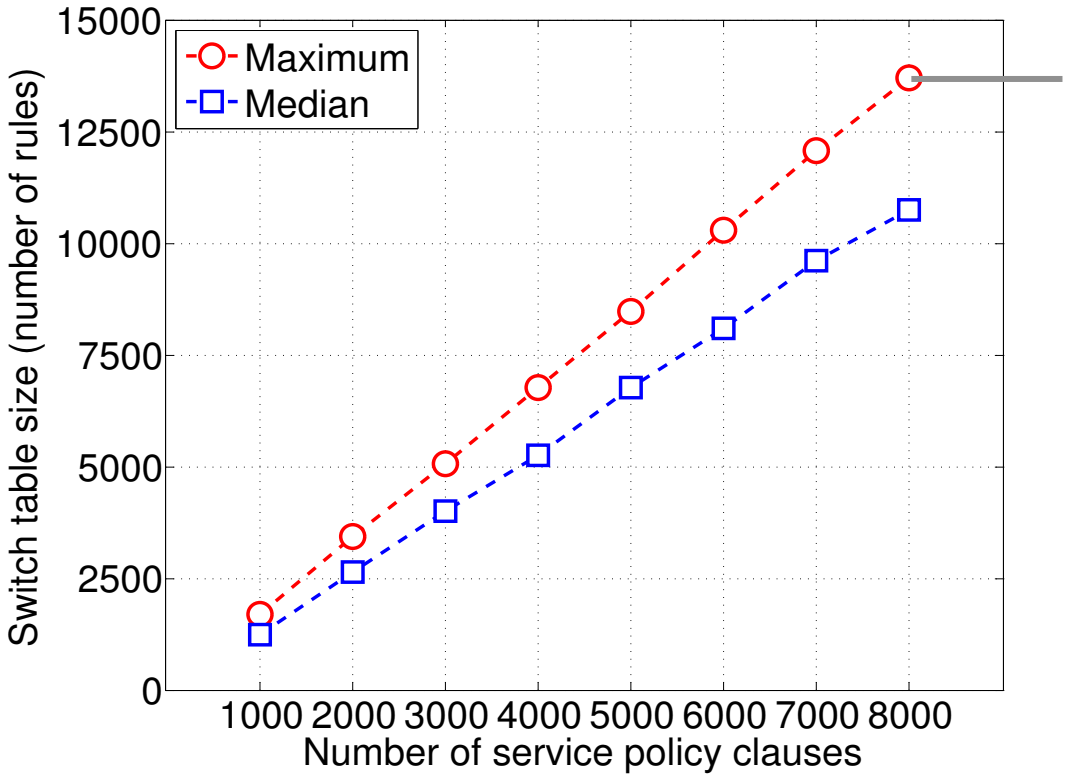


Switches table size increase linearly wrt to the # of policy paths



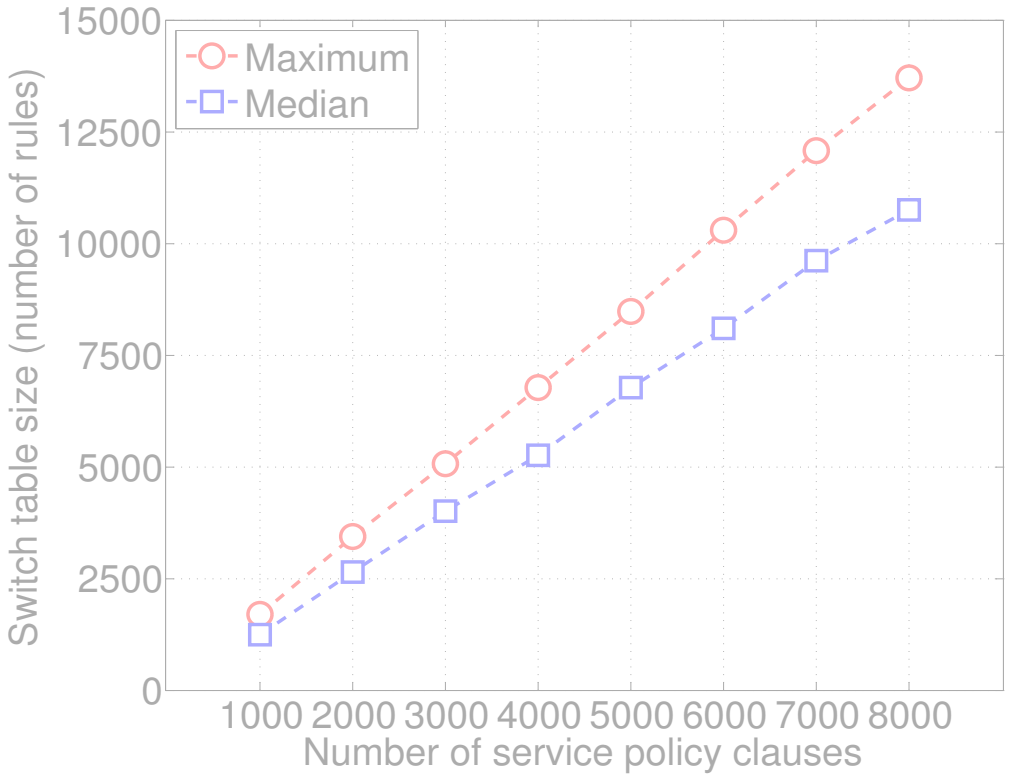
Only 5k entries are required to support 4k policy paths

Switches table size increase linearly wrt to the # of policy paths



In the worst case, 8k policy paths require 13.6k entries

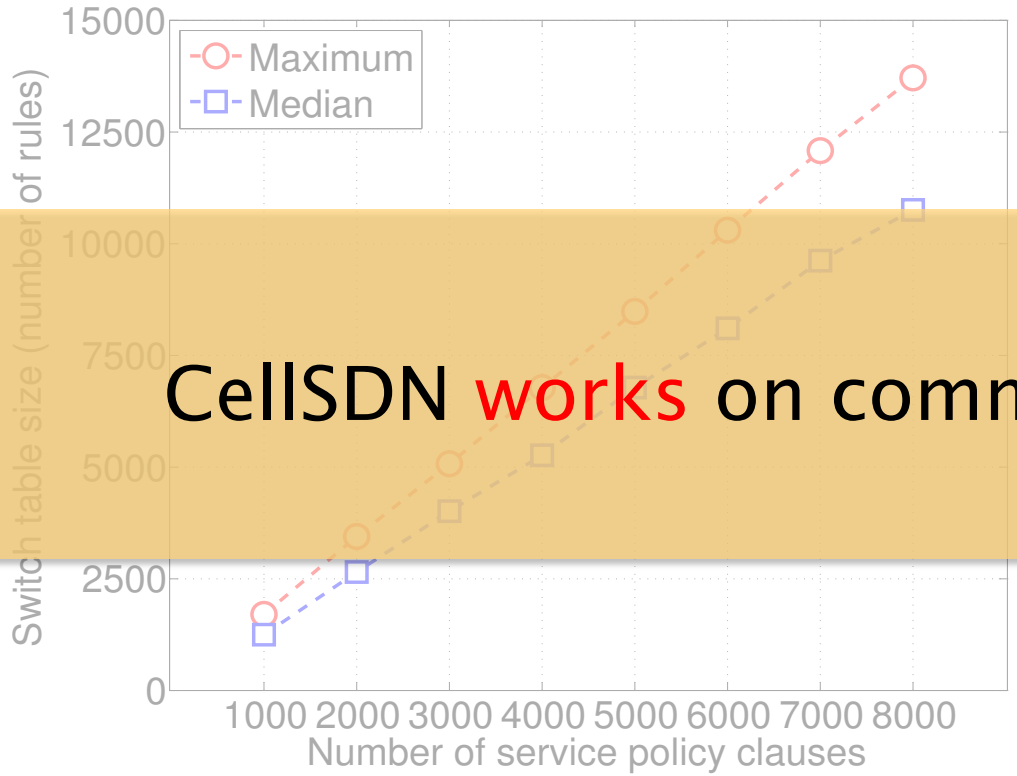
Switches table size increase linearly wrt to the # of policy paths



In the worst case, 8k policy paths require 13.6k entries

Today, operators require a few hundreds policies

Switches table size increase linearly wrt to the # of policy paths



CellSDN works on commodity switches

CellSDN: Taking control of cellular core networks

Architecture

software-defined network

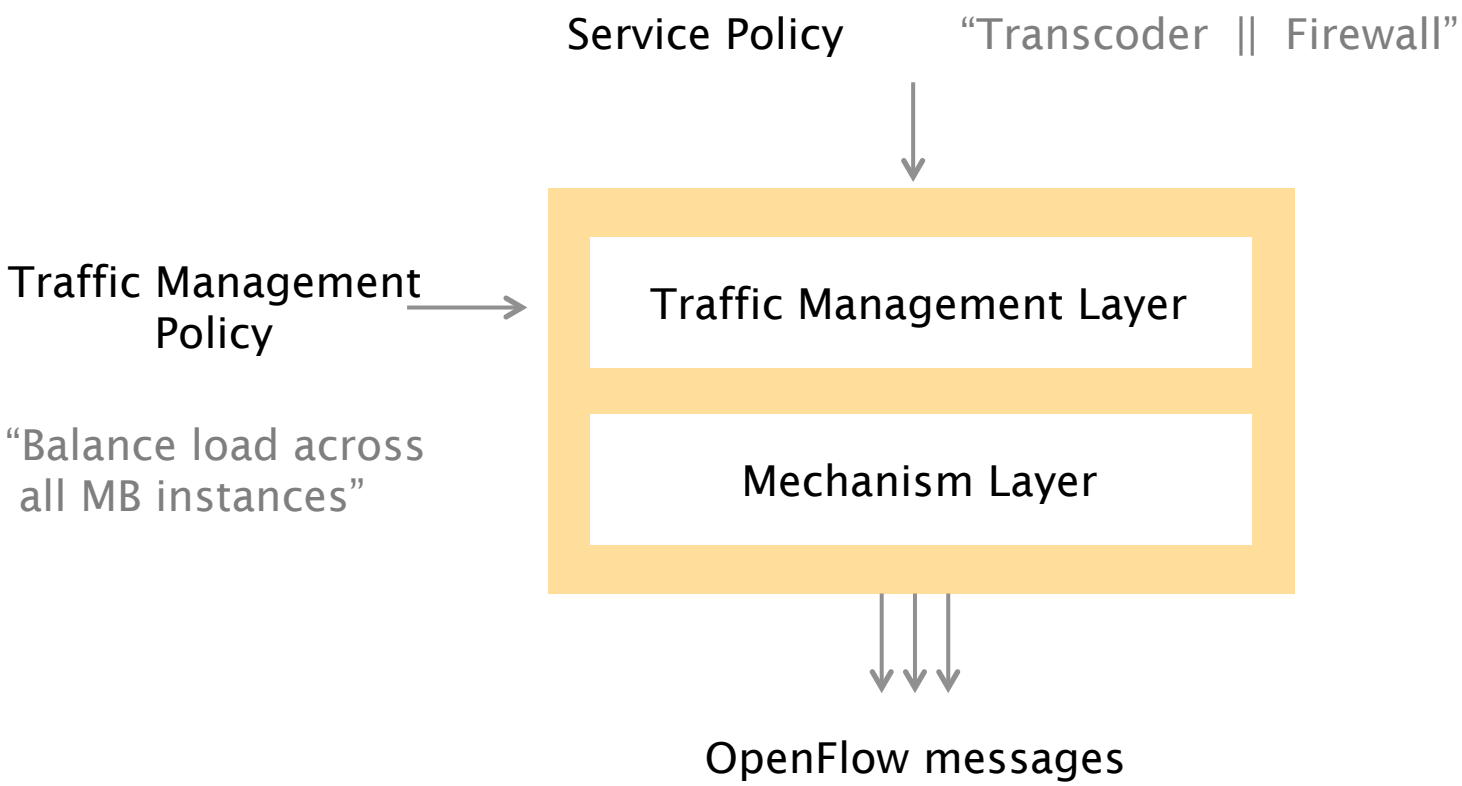
Scaling the data-plane

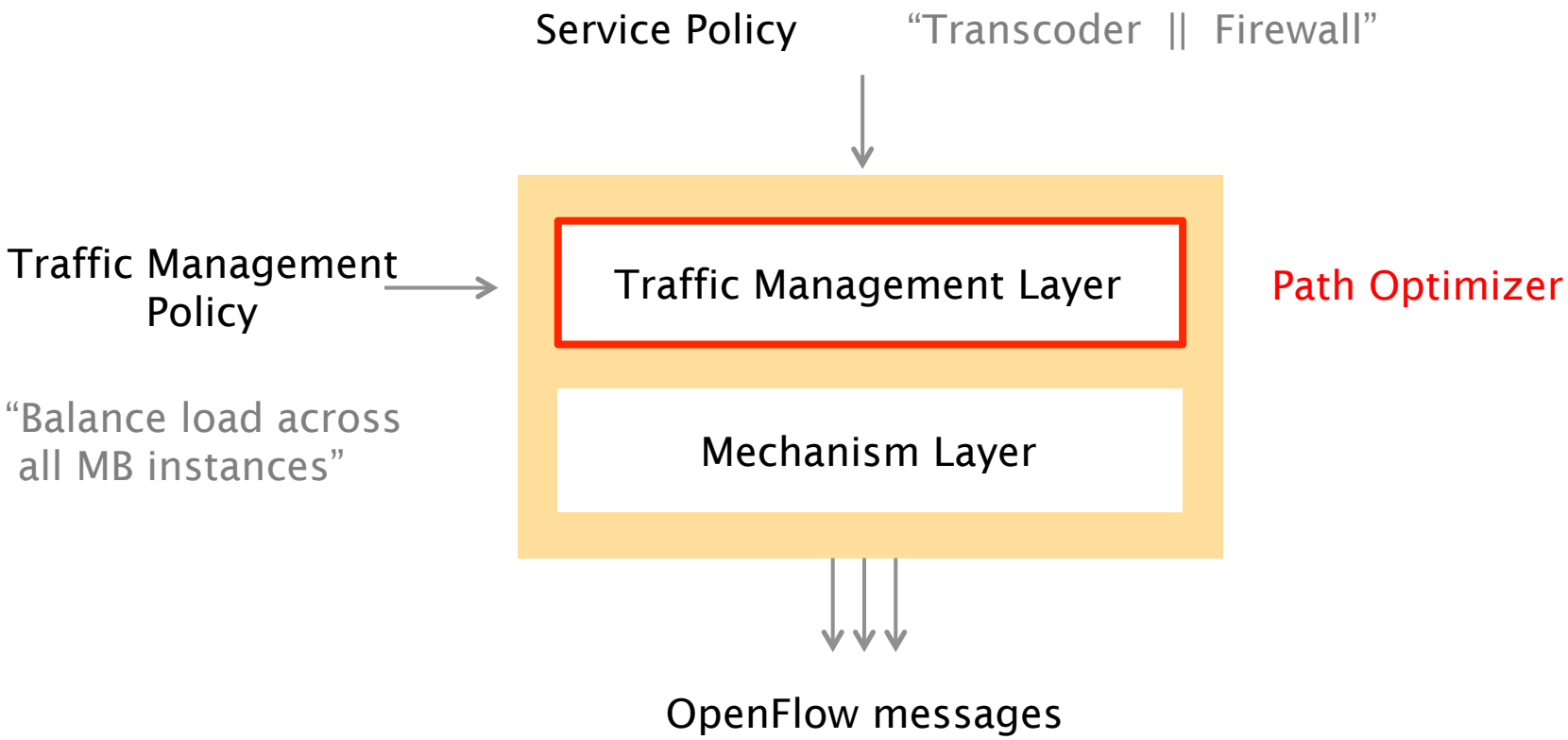
multi-dimensional tagging

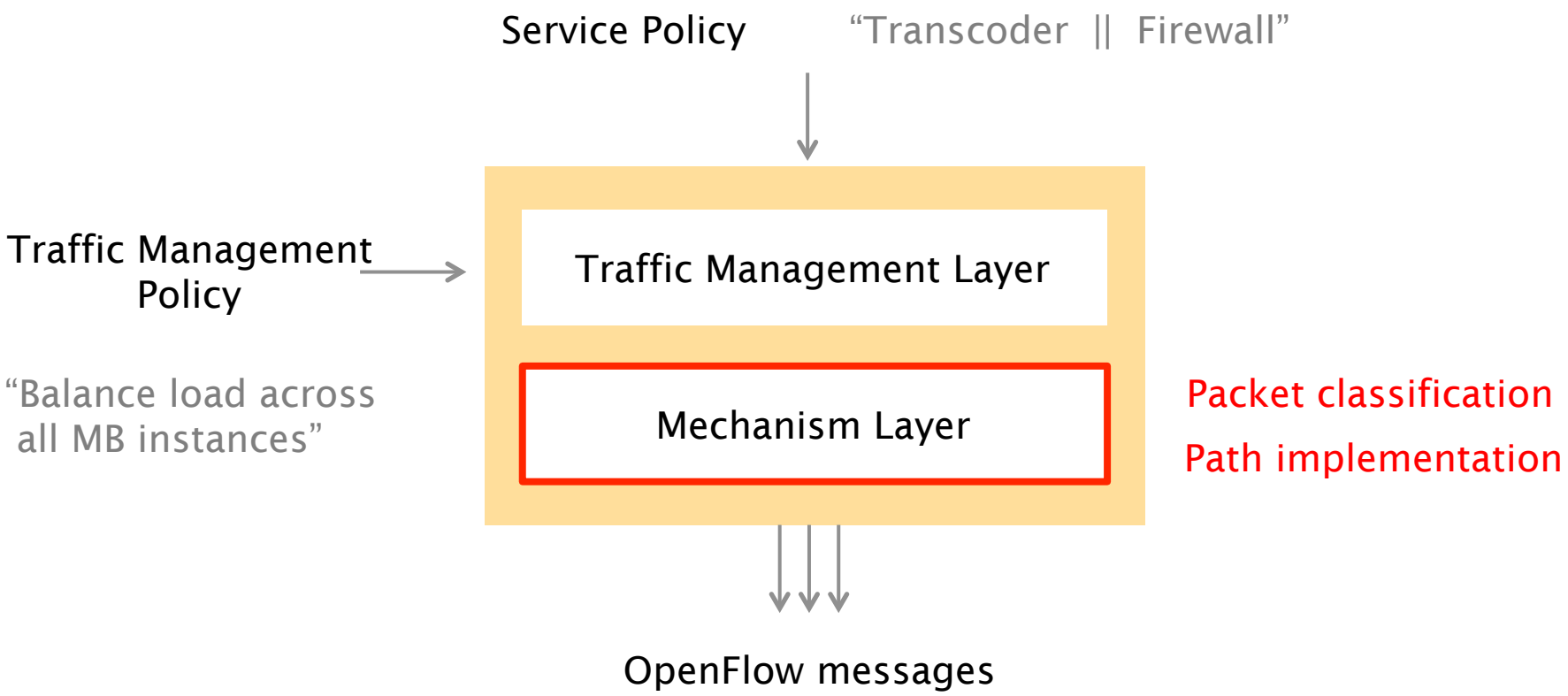
3 Scaling the control-plane

tasks delegation

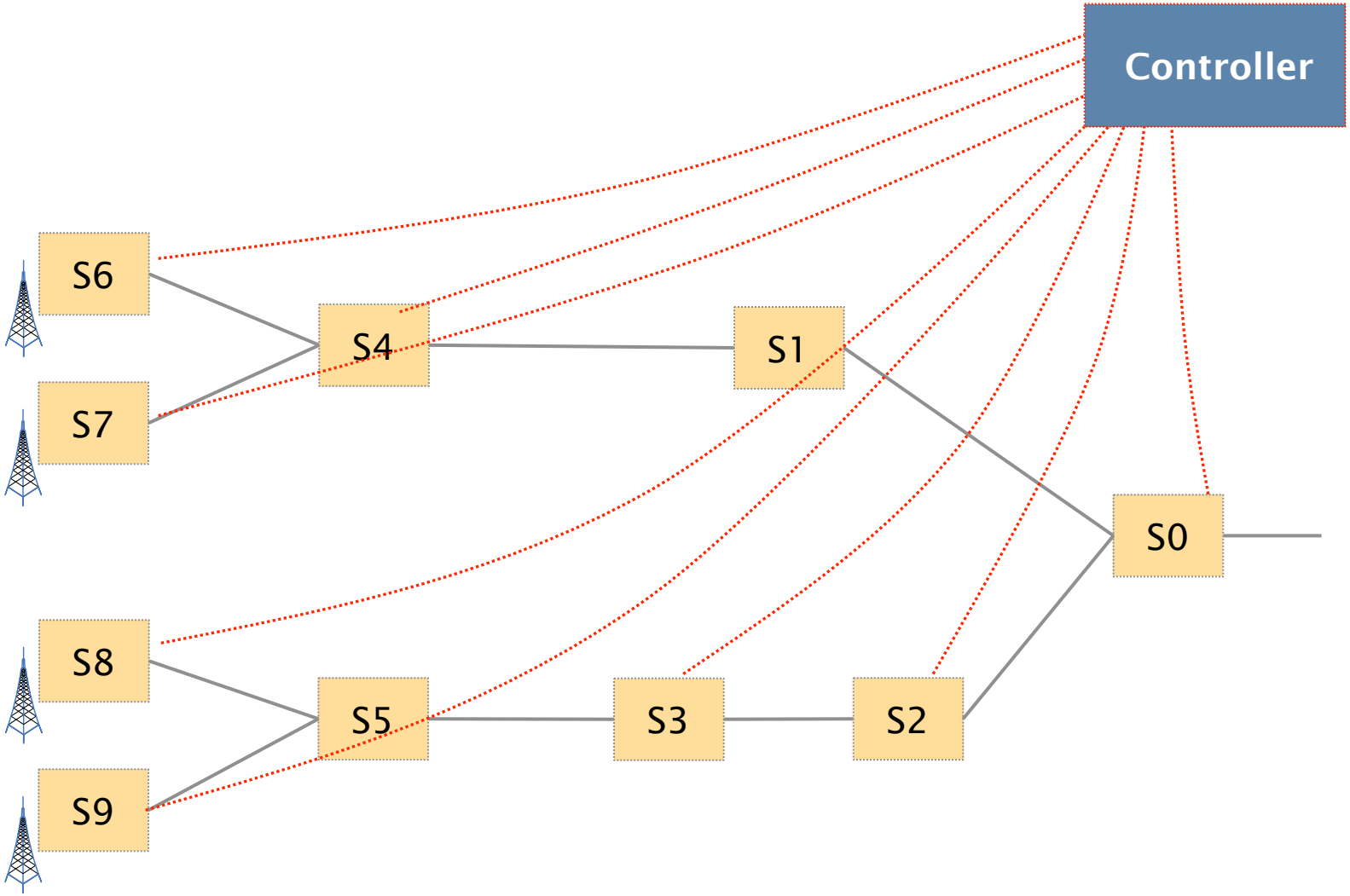
CellSDN controller separates traffic management from rules installation



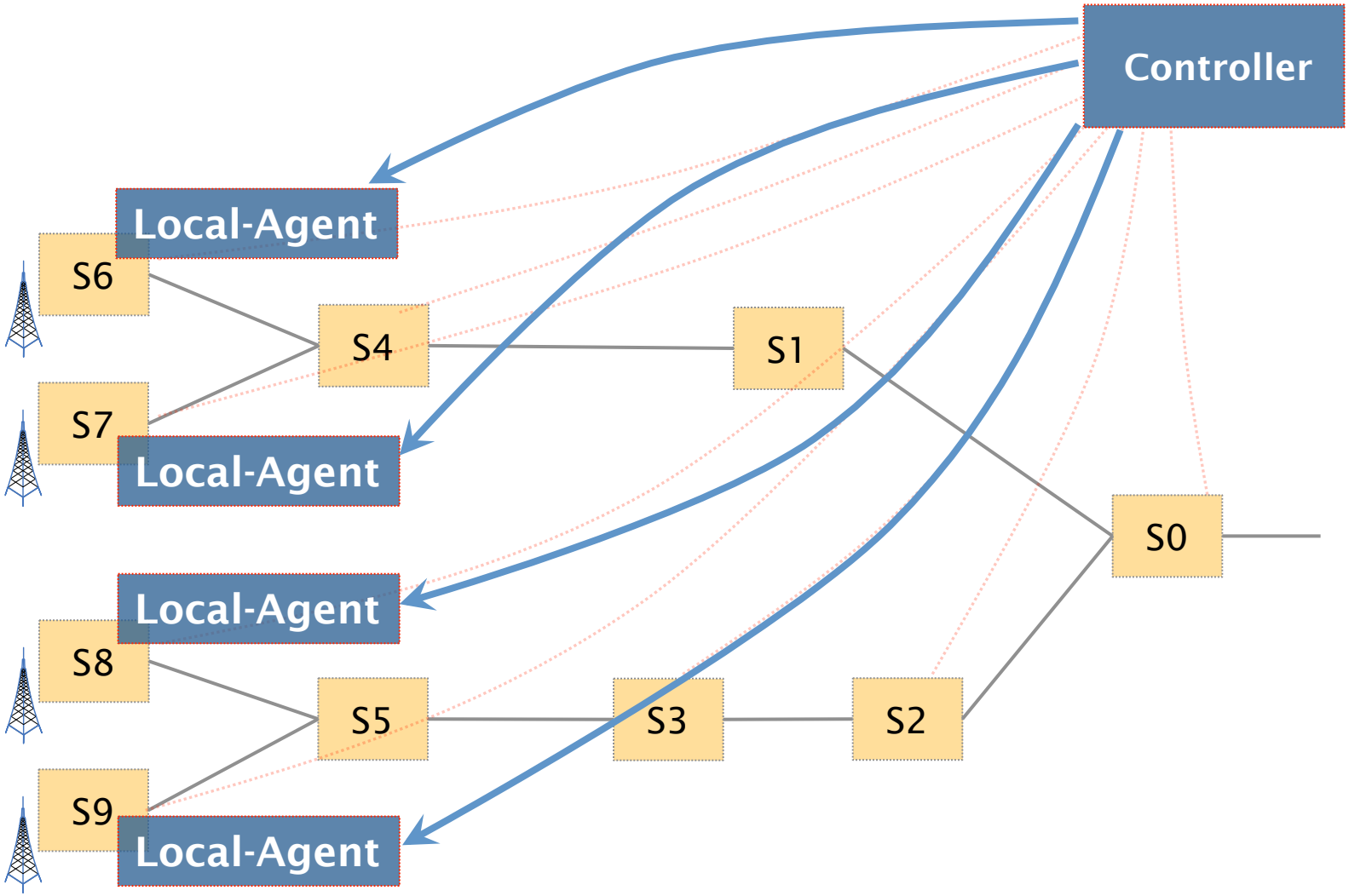

Service Policy
"Transcoder || Firewall"
Traffic Management Policy
"Balance load across all MB instances"
Traffic Management Layer
Mechanism Layer
Path Optimizer
OpenFlow messages


Service Policy
“Transcoder || Firewall”
Traffic Management Policy
Traffic Management Layer
“Balance load across all MB instances”
Mechanism Layer
Packet classification
Path implementation
OpenFlow messages

To scale, CellSDN uses a hierarchical controller



Most of the tasks are delegated to local-agents



Local-agents act as cache, reducing the load on the main controller

Local agents handle *locally* most frequent events

- cache a list of packet classifiers
- contact central controller upon cache miss
- tag flows

The central controller deals with less frequent, but more complex events

Local agents handle *locally* most frequent events

- cache a list of packet classifiers
- contact central controller upon cache miss
- tag flows

Central controller *globally* handle less frequent events

- UE arrival, handoff
- topology changes
- dynamic policies

CellSDN control-plane can handle the load of large cellular networks

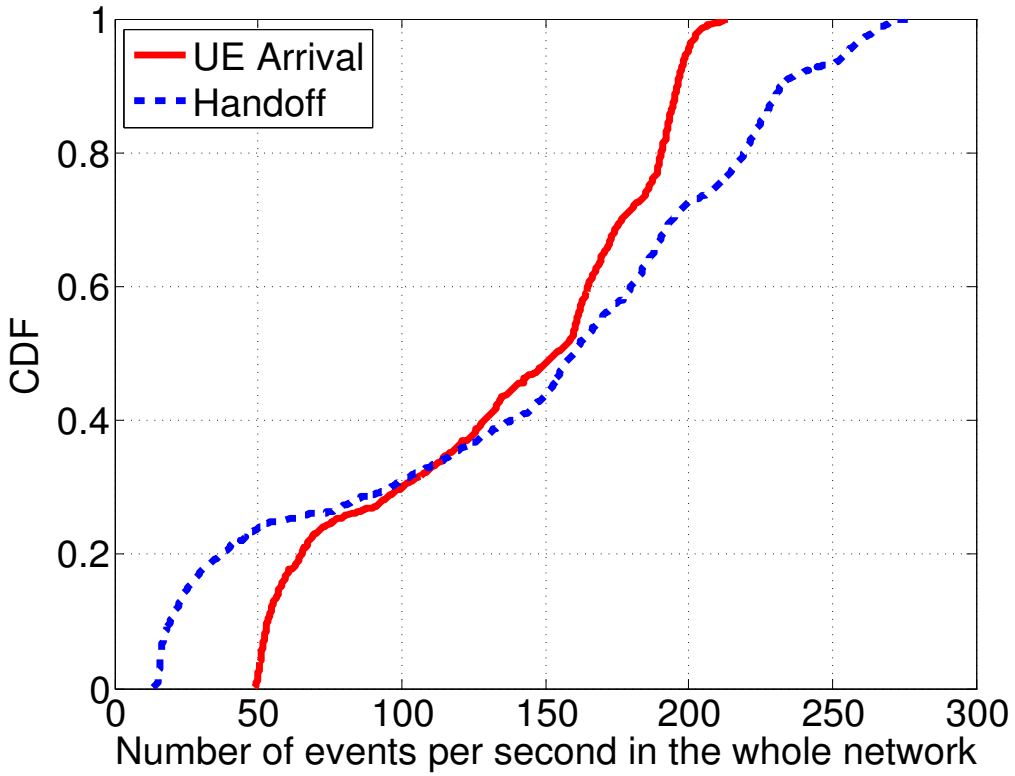
Dataset

- 1 week of traces from a large LTE network
- 1500 base stations
- 1 million users

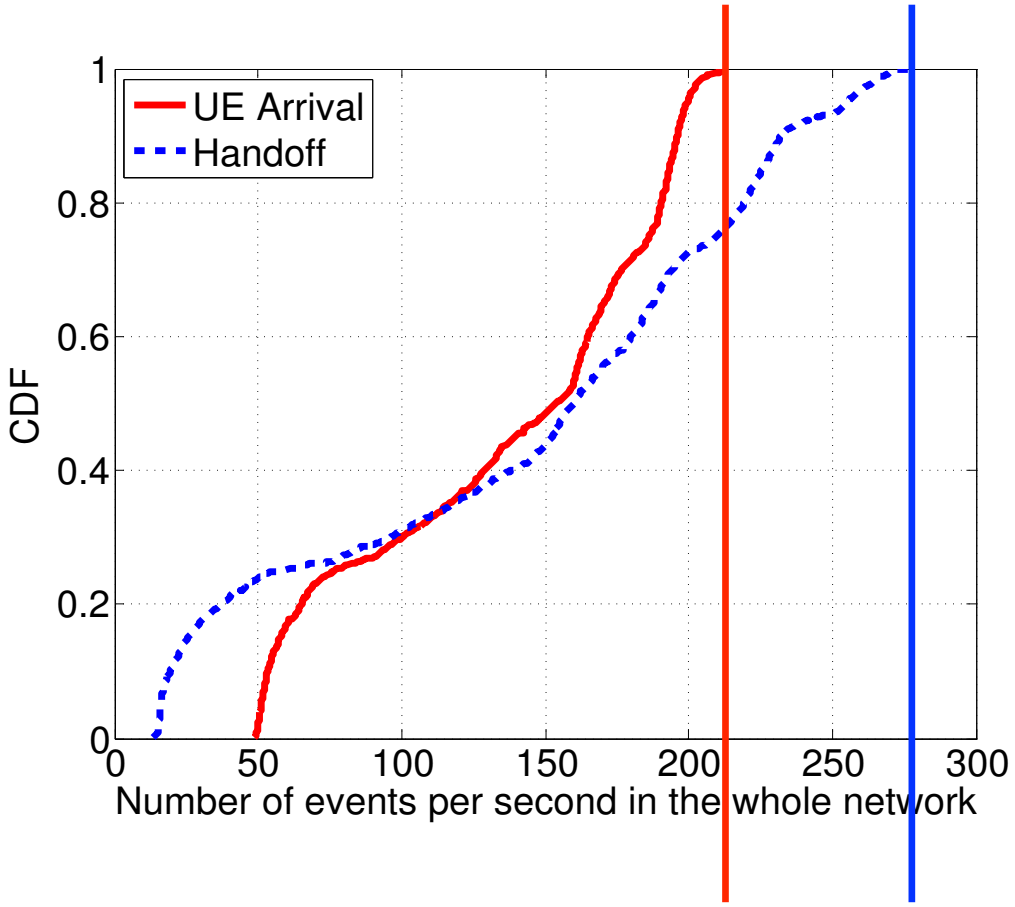
Evaluation

- # of events per second
- # of active users per second

The number of events going to the main controller is small

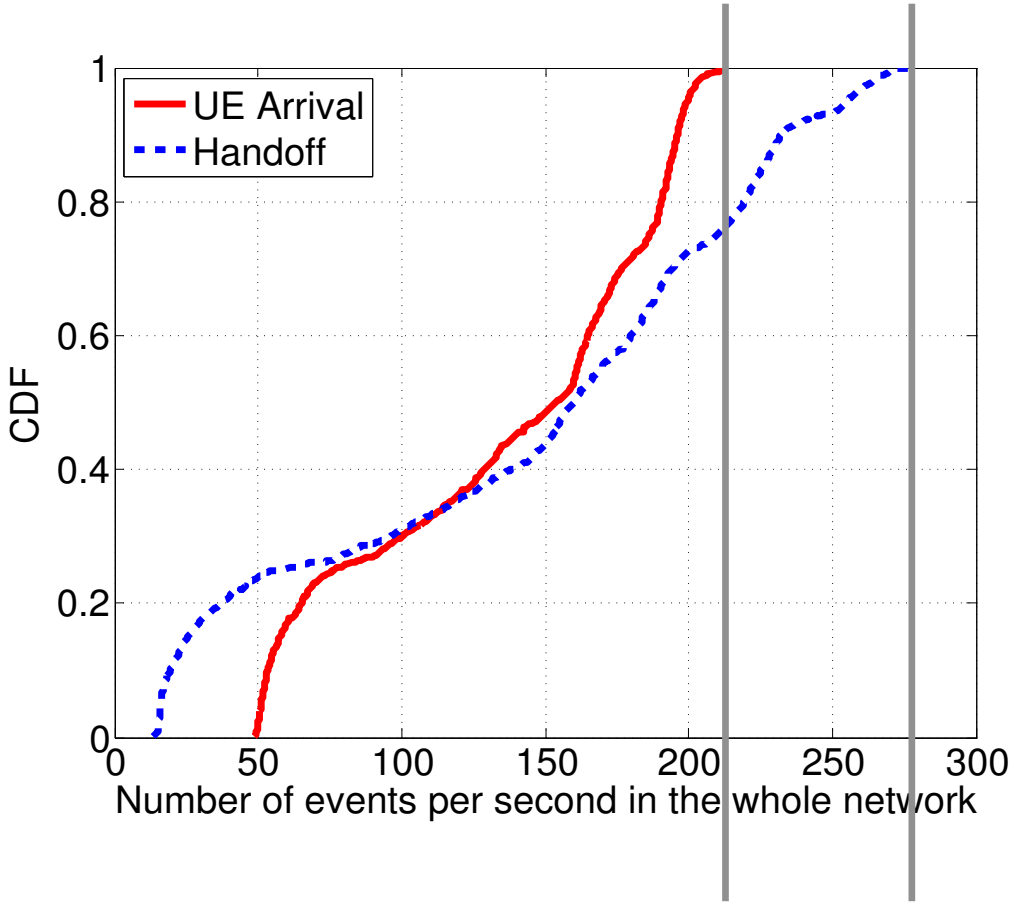


The number of events going to the main controller is small



99th percentile 214/s 280/s → Total << 1000

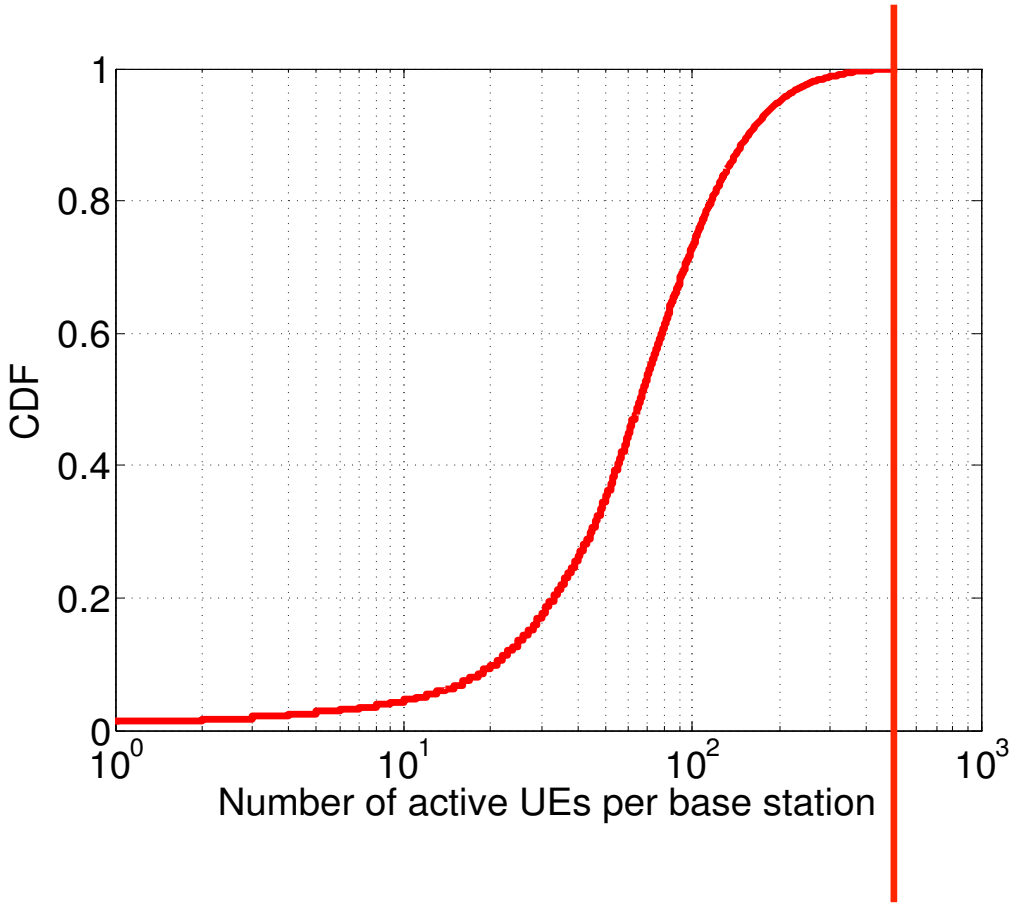
The number of events going to the main controller is small



Today's controllers can process tens of thousands events/s

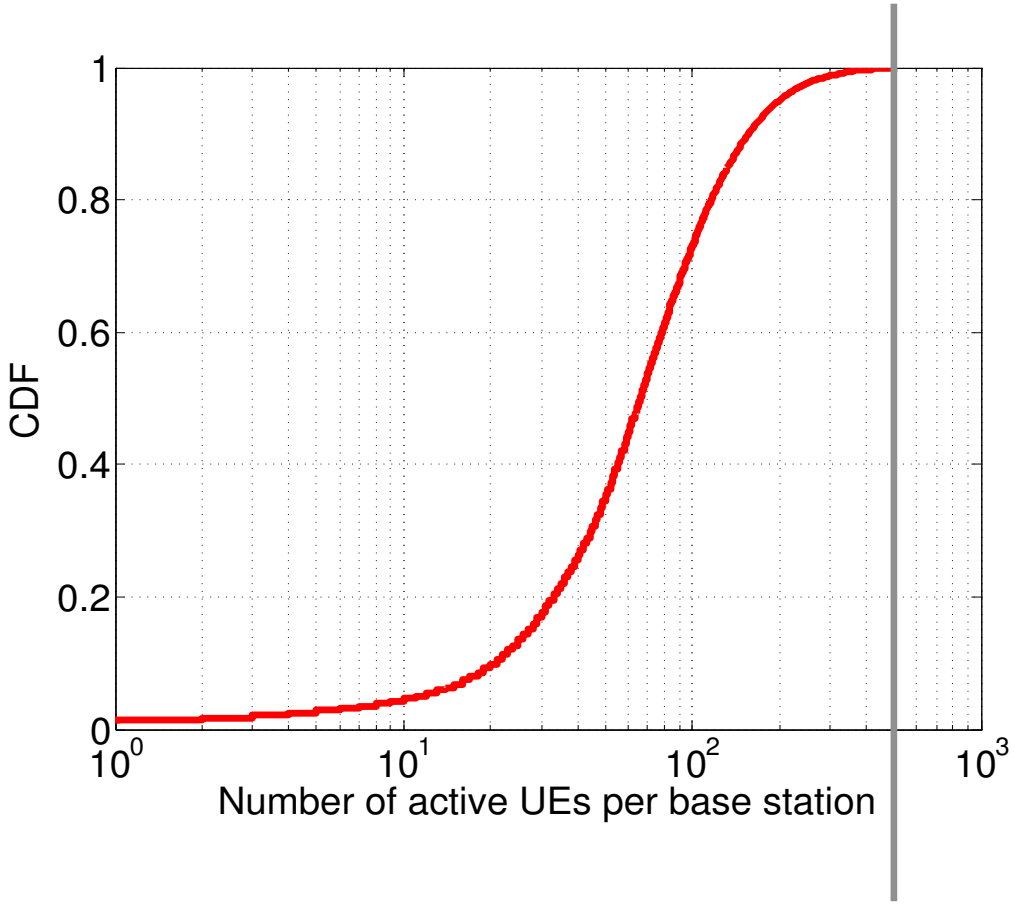
99th percentile 214/s 280/s ⟶ Total << 1000

The number of flows handled by the local-agent is small



99th percentile 514/s → ~ 5k flows

The number of flows handled by the local-agent is small



Today's controllers can process tens of thousands events/s

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CellSDN: Taking control of cellular core networks

Architecture

software-defined network

Scaling the data-plane

multi-dimensional tagging

Scaling the control-plane

tasks delegation

CellSDN enables flexible and cost-effective cellular networks

CellSDN supports flexible fine-grained policies

CellSDN achieves scalability with

- Multi-dimensional aggregation
- Asymmetric edge design
- Hierarchical controller

CellSDN: Taking control of cellular core networks

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Tue 9 April 2013