ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

SDN Controller Design for Dynamic Chaining of Virtual Network Functions.

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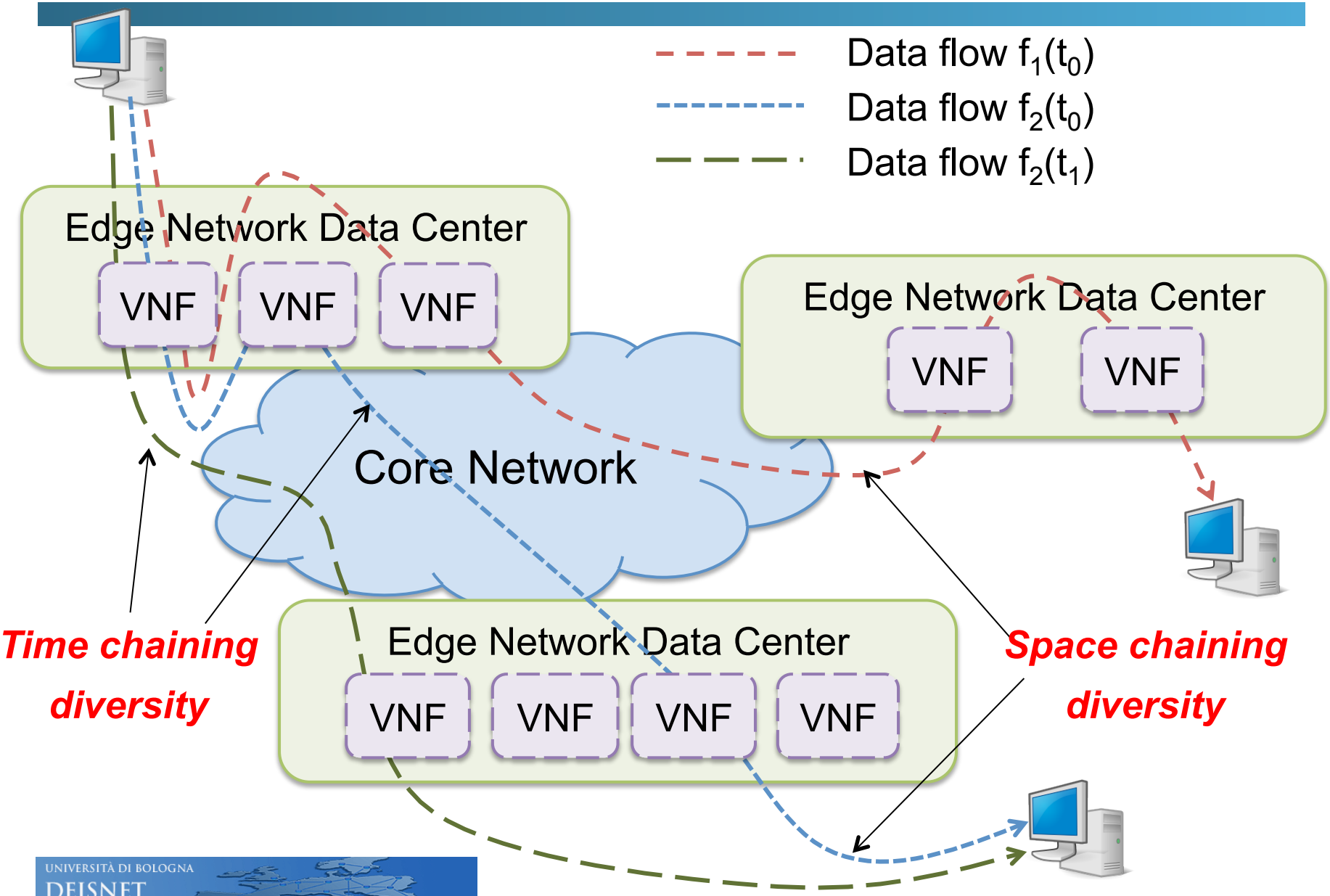
Context

- Network programmability is becoming feasible owing to recently developed key technologies
  - SDN
  - NFV
  - hardware capable of supporting them

- NFV as a flexible solution for replacing vendor dependent middle-boxes

- Paradigm shift will take place mainly at the **network edges**

NFV Chaining & dynamic traffic steering



Goal

- Suggest a design methodology for implementing SDN control plane capable of
  - Dynamically steering traffic towards required VNF
  - Achieving fully adaptive service chaining
- Case study:
  - Layer 2 (L2) Edge network
  - OpenStack cloud platform

- What about SDN controller design?
  - Mealy Machine abstraction as general approach to service chain reconfiguration
  - example: dynamic enforcement of QoS in a multi-tenant scenario

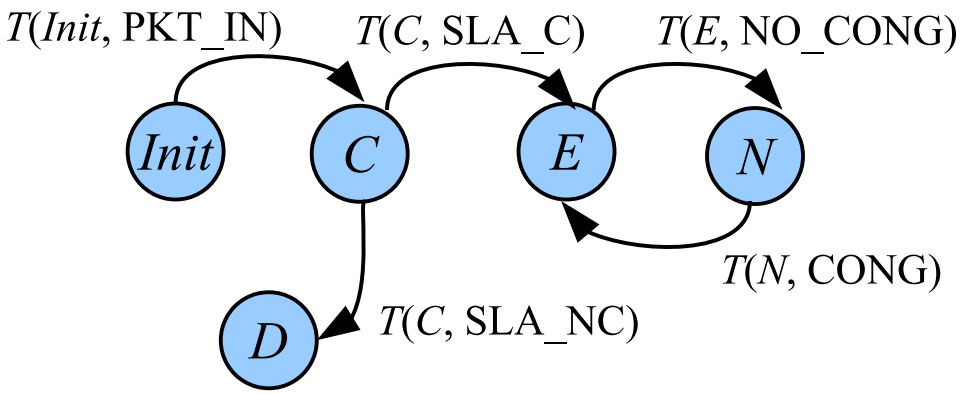
SDN controller abstraction

- Finite State Machine (FSM)
- Formal definitions:
  - *f*: traffic stream
  - *s*: set of state

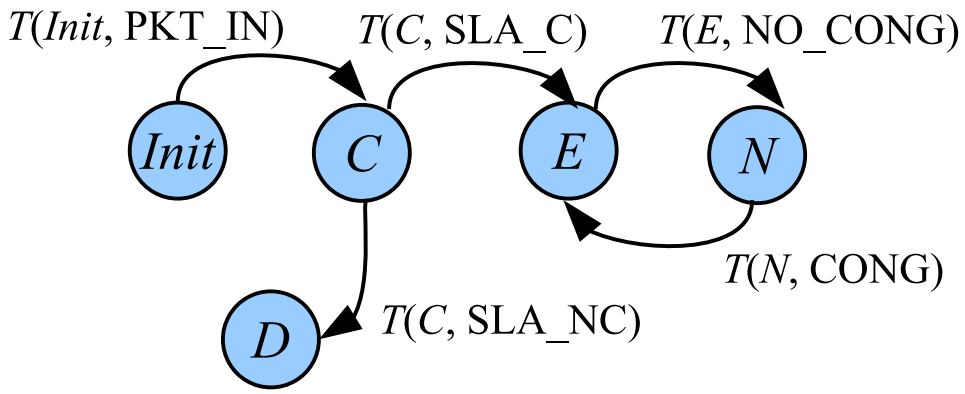
    $s \in \{Init, C, E, N, D\}$
  - *i*: set of input

    $i \in \{PKT\_IN, SLA\_C, SLA\_NC, CONG, NO\_CONG\}$
  - *A(f,s,i)*: actions (SDN technology dependent)
  - *T*: state transition function

    $(s,i) \rightarrow (s', A(f,s,i))$



States definition



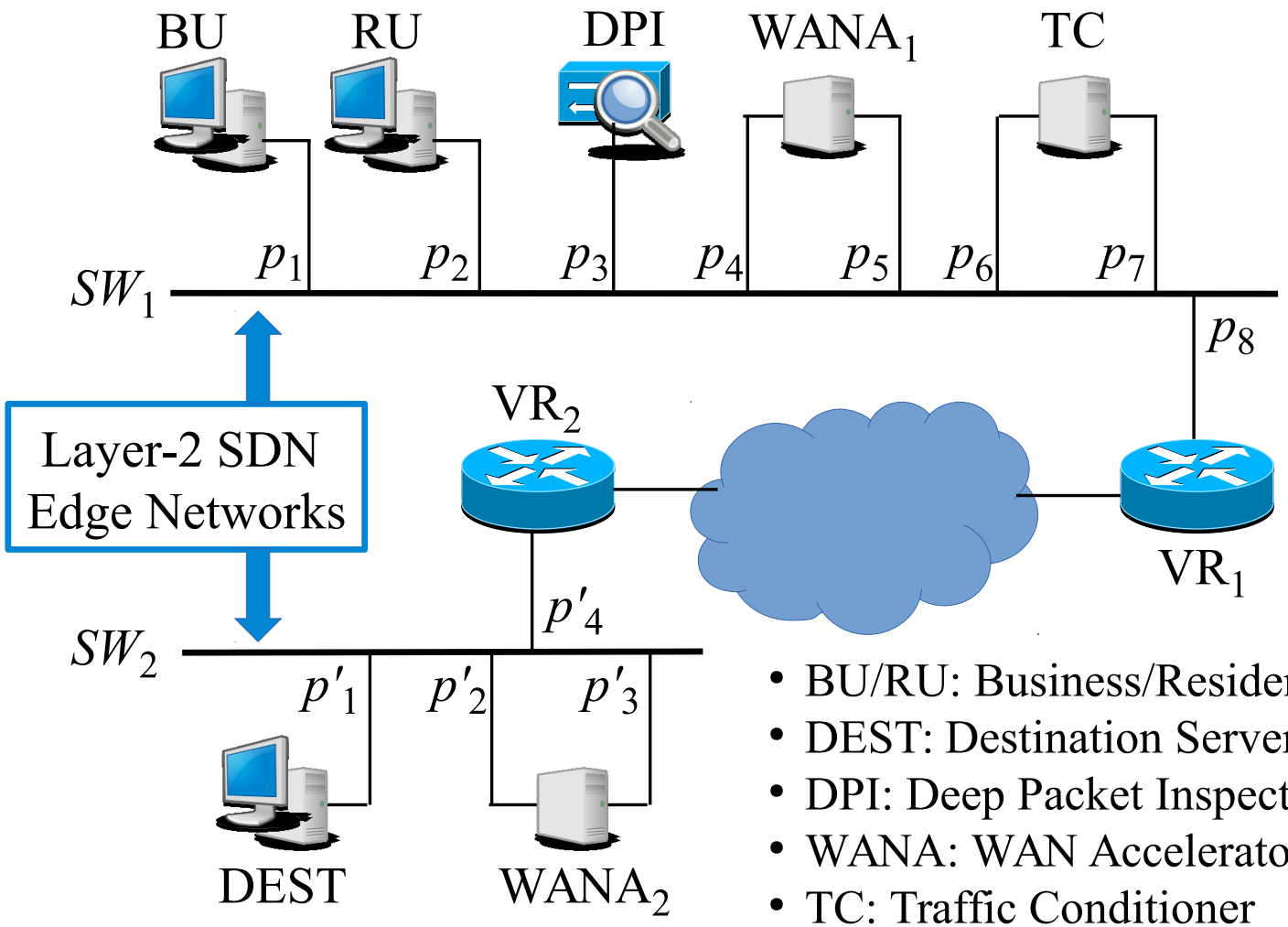
- State definition:
  - *Init*: flow independent rules are installed in the network nodes
  - *C*: flow *f* is analyzed and classified
  - *E*: flow *f* is strictly subject to QoS enforcement
  - *N*: flow *f* is not strictly subject to QoS enforcement
  - *D*: flow *f* is subject to policing actions

- Additional parameters can be defined

Genaral parameters

- $NT = \{SW_1, SW_2, \ldots, SW_{NSW}\}$ set of switch
- $SW_j = \{p_1, p_2, \ldots, p_{Np,j}\}$ set of ports
- $U = \{u_1, u_2, \ldots, u_{Nu}\}$ set of users
- $NF = \{F_1, F_2, \ldots, F_{NF}\}$ set of VNFs
- $Ch(f, s) = \{F_{l1}, F_{l2}, \ldots, F_{ln(f,s)}\}$ service chain of $n(f,s)$ VNFs applied to f in state s
- Getting topology information:
  - $(SW_j, p_m) = get\_port(u_k)$
  - $(SW_j, p_m) = get\_in\_port(F_l, d)$
  - $(SW_j, p_m) = get\_out\_port(F_l, d)$
- $SW_j \in NT$, $p_m \in SW_j$, $u_k \in U$, $F_l \in NF$ and $d \in \{inbound, outbound\}$
- $flow\_mod(SW_j, cmd, opts, match, fwdlist)$

Case study topology: OpenStack platform



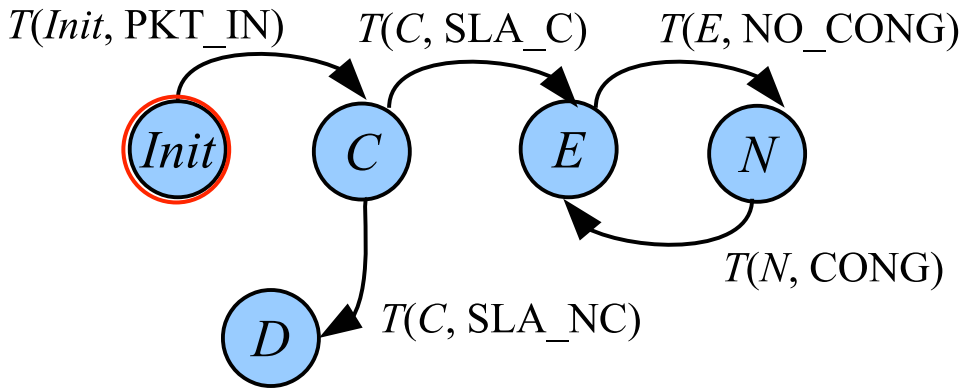
- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router

Case study definitions

- $NT = \{SW_1, SW_2\}$
- $U = \{BU, RU, DEST\}$
- $NF = \{DPI, TC, WANA_1, WANA_2, VR_1, VR_2\}$
- Service chain definition:
  - $Ch(f_{BU}, Init) = Ch(f_{BU}, D) = nill$
  - $Ch(f_{BU}, C) = \{DPI \ \& \ VR_1\}$
  - $Ch(f_{BU}, E) = \{WANA_1, VR_1\}$
  - $Ch(f_{BU}, N) = \{VR_1\}$

- What about actions during state transition?

Init state actions



Initialization

1: **for all** F_l in $\{\text{TC}, \text{WANA}_1, \text{WANA}_2\}$ **do**
2: $(sw_{\text{in}}, p_{\text{in}}) = get\_in\_port(F_l, \text{outbound})$
3: $(sw_{\text{out}}, p_{\text{out}}) = get\_out\_port(F_l, \text{outbound})$
4: *fwdlist* = append("drop")
5: **for all** (sw, p) in $\{(sw_{\text{in}}, p_{\text{in}}), (sw_{\text{out}}, p_{\text{out}})\}$ **do**
6: *match* = "ofp_match(in_port = p, dl_type = ARP_TYPE, dl_dst = ETHER_BCAST)"
7: $flow\_mod(sw, \text{ADD}, \text{nil}, match, fwdlist)$
8: **end for**
9: **end for**

Init state actions

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- Installing flow independent rules
  - ARP storm avoidance

T(Init, PKT_IN) = (C, A(f_{BU},Init,PKT_IN))

1: $(sw, p_{\text{in}}) = get\_port(\text{BU})$
2: $(sw, p_{\text{out},0}) = get\_in\_port(\text{DPI}, \text{outbound})$
3: $(sw, p_{\text{out},1}) = get\_in\_port(\text{VR}_1, \text{outbound})$
4: *fwdlist* = append("ofp_action_output(port=$p_{\text{out},0}$)")
5: *fwdlist* = append("ofp_action_vlan_vid(vlan_id = internal_vid)")
6: *fwdlist* = append("ofp_action_output(port=$p_{\text{out},1}$)")
7: *opts* = "hto=t_{out}, priority=h"
8: *match* = "ofp_match(in_port=p_{in},$get\_match(f_{\text{BU}})$)"
9: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$
10: $(sw, p_{\text{in}}) = get\_out\_port(\text{VR}_1, \text{inbound})$
11: $(sw, p_{\text{out},0}) = get\_port(\text{BU})$
12: $(sw, p_{\text{out},1}) = get\_in\_port(\text{DPI}, \text{inbound})$
13: *fwdlist* = append("ofp_action_strip_vlan_vid()")
14: *fwdlist* = append("ofp_action_output(port=$p_{\text{out},0}$)")
15: *fwdlist* = append("ofp_action_output(port=$p_{\text{out},1}$)")
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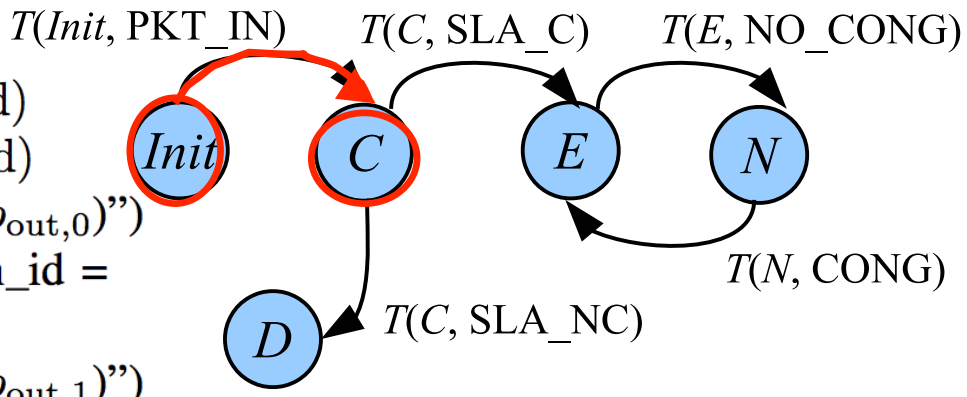

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16: *match* = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
17: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

Getting topology information

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15: *fwdlist* = append("ofp_action_output(port=$p_{\text{out},1}$)")
16: *match* = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
17: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

OpenFlow actions

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16: *match* = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
17: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

Installing rule on the switch

T(Init, PKT_IN) = (C, A(f_{BU},Init,PKT_IN))

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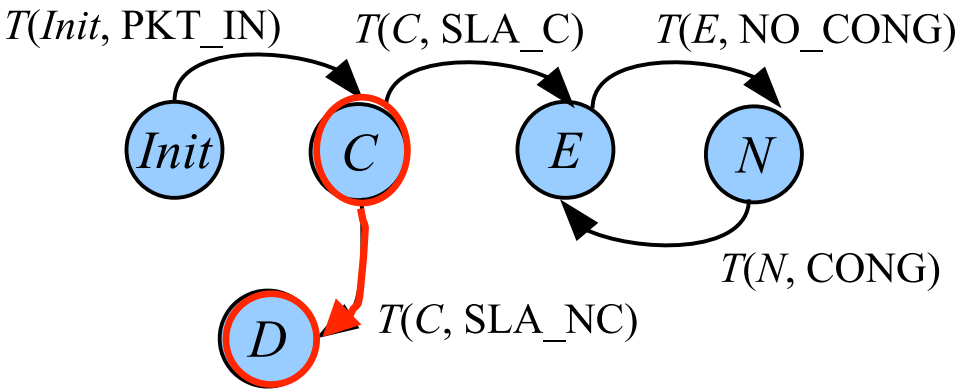
16: *match* = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
17: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

Handling bidirectional flows

T(C, SLA_NC) = (D, A(f_{BU},C,SLA_NC))

1: $(sw, p_{\text{in}}) = get\_port(\text{BU})$
2: $fwdlist$ = append("drop")
3: $opts$ = "priority=$h + 1$"
4: $match$ = "ofp_match(in_port=p_{in},$get\_match(f_{\text{BU}})$)"
5: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$



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3: $opts$ = "priority=$h + 1$"
4: $match$ = "ofp_match(in_port=p_{in},$get\_match(f_{\text{BU}})$)"
5: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

Dropping non compliant traffic

T(C, SLA_C) = (E, A(f_{BU},C,SLA_C))

1: $(sw, p_{\text{in}}) = get\_port(\text{BU})$
2: $(sw, p_{\text{out}}) = get\_in\_port(\text{WANA}_1, \text{outbound})$
3: $fwdlist$ = append("ofp_action_output(port=p_{out})")
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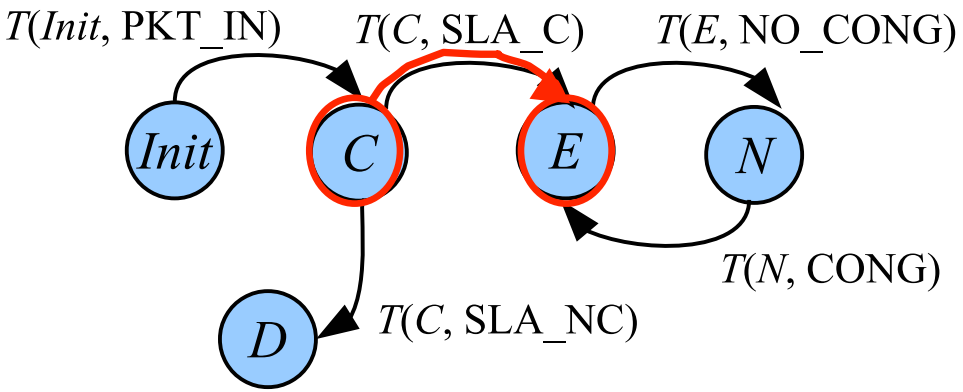

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- Traffic steering:
  - First sent to WANA_1
  - Then to VR_1
  - Reverse order for inbound traffic case

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11: $match$ = "ofp_match(in_port=p_{in},$get\_match(f_{\text{BU}})$)"
12: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$
13: $(sw, p_{\text{in}}) = get\_out\_port(\text{VR}_1, \text{inbound})$
14: $(sw, p_{\text{out}}) = get\_in\_port(\text{WANA}_1, \text{inbound})$
15: $fwdlist$ = append("ofp_action_strip_vlan_vid()")
16: $fwdlist$ = append("ofp_action_output(port=p_{out})")
17: $match$ = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
18: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$
19: $(sw, p_{\text{in}}) = get\_out\_port(\text{WANA}_1, \text{inbound})$
20: $(sw, p_{\text{out}}) = get\_port(\text{BU})$
21: $fwdlist$ = append("ofp_action_output(port=p_{out})")
22: $match$ = "ofp_match(in_port=p_{in},$get\_match(f'_{\text{BU}})$)"
23: $flow\_mod(sw, \text{ADD}, opts, match, fwdlist)$

- Traffic steering:
  - First sent to WANA_1
  - Then to VR_1
  - Reverse order for inbound traffic case

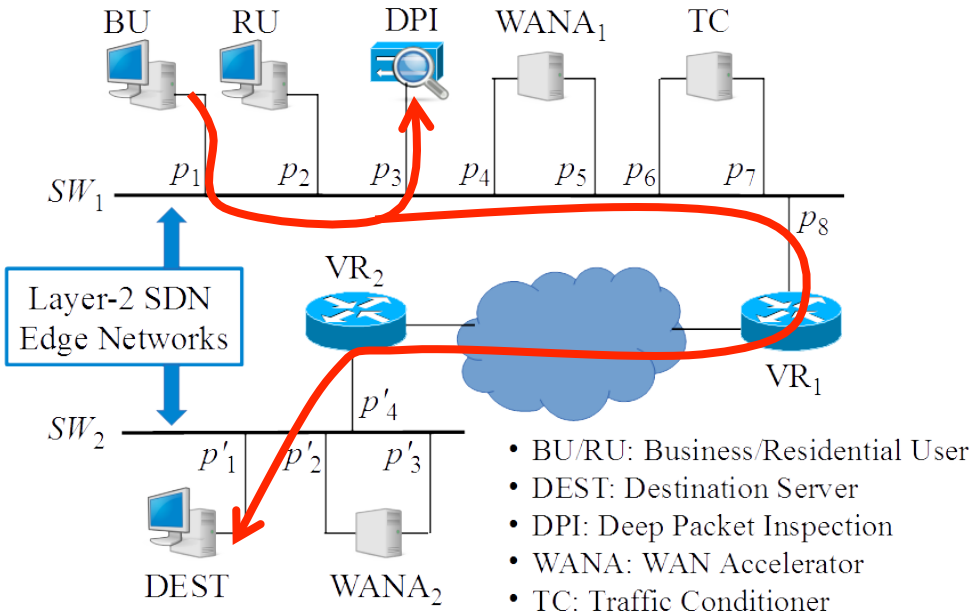
State transitions: observations

- Others state transitions can be easily derived from previous cases:
  - *T(E, NO_CONG) = (N, A(f_{BU},E, NO_CONG))*: steps similar to those of state transition from *Init* to *C*
  - *T(N, CONG) = (E, A(f_{BU},N, CONG))*: steps similar to those of state transition from *E* to *N* (*flow_mod* command changed to DELETE)
- VNF chaining is driven by current network conditions
- Steering actions can also be replicated for RU flows

Testbed setup

- Network topology created with OpenStack platform
  - POX SDN Controller
  - BU, RU, DPI (nDPIReader), $WANA_1$ (TrafficSqueezer) and TC implemented as VMs
  - Destination edge network outside OpenStack cluster
- Throughput measured at each VNF ports
  - DPI
  - $WANA_1$
  - TC
  - VR_1
- Iperf traffic generator: 100 Mbit/s

Proof of concept: SDN controller design

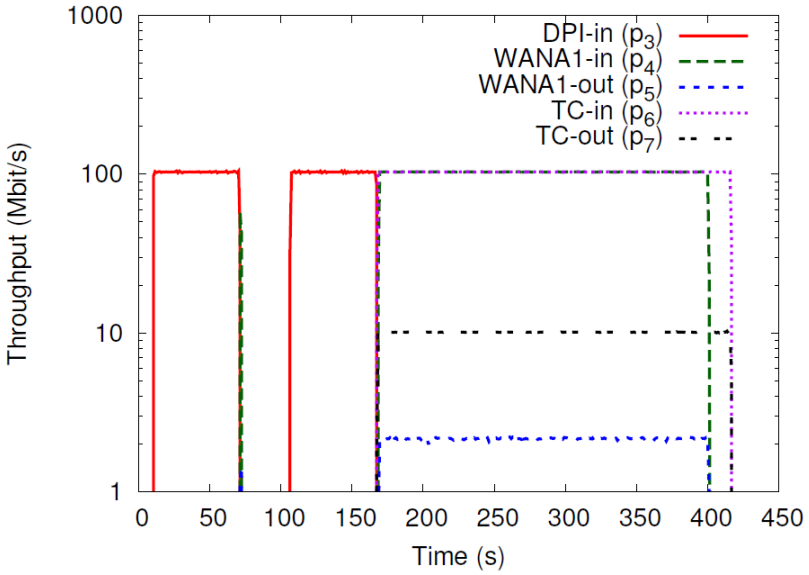


- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router

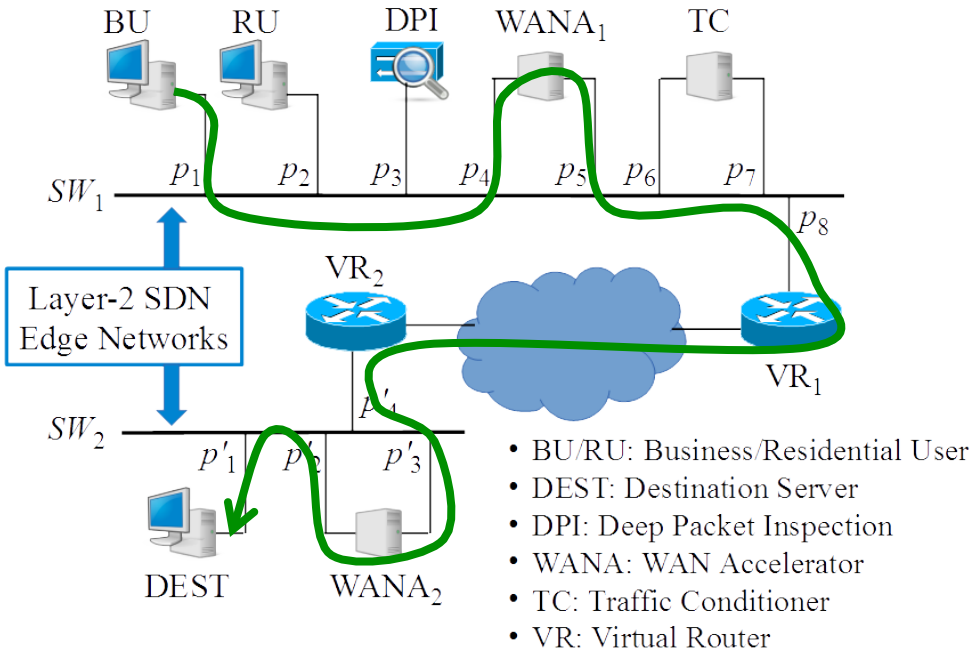
Phase 1: classification

Rules installed in SW1:

- Traffic from to DEST is forwarded both to VR1 and DPI
- Similarly for inbound packets



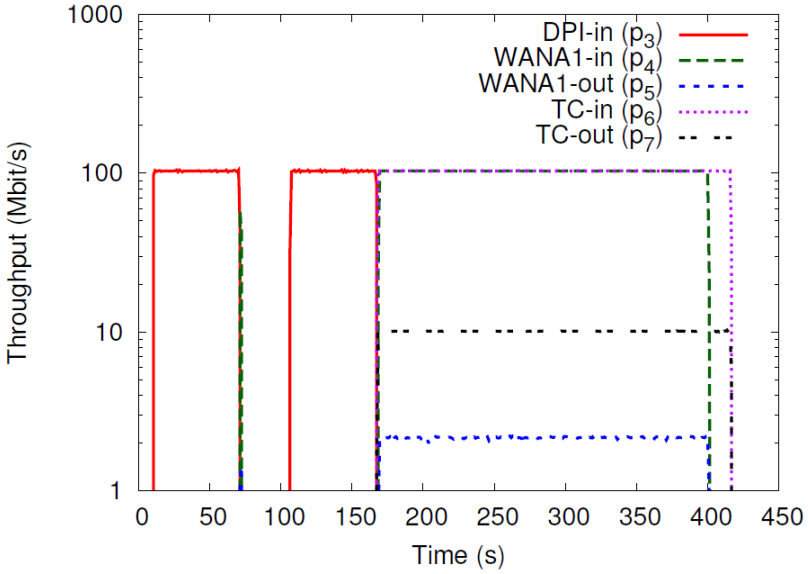
Proof of concept: SDN controller design



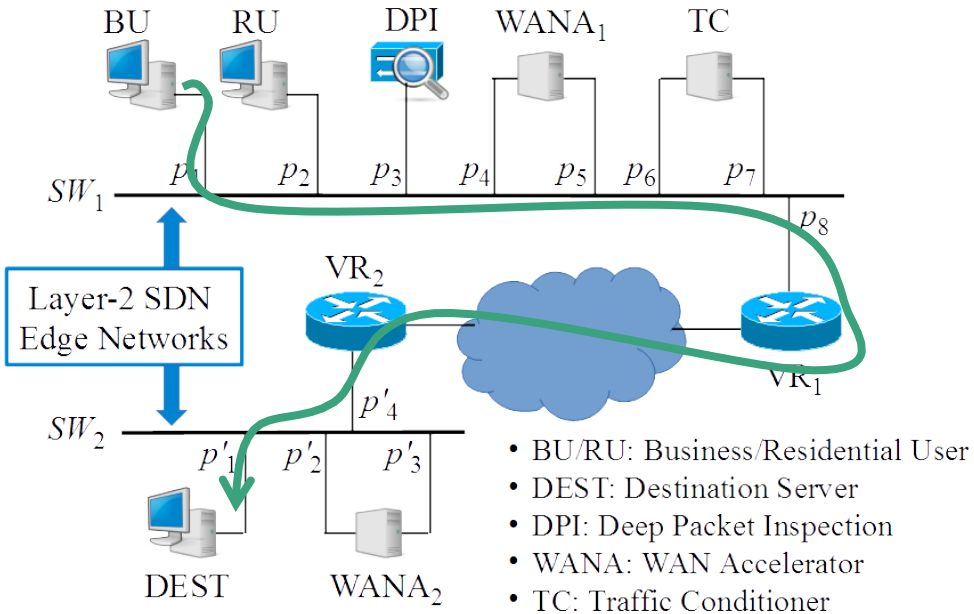
Phase 2: SLA compliance

Rules installed in SW1:

- Traffic from to DEST is forwarded to VR1 via WANA1
- Similarly for inbound packets



Proof of concept: SDN controller design

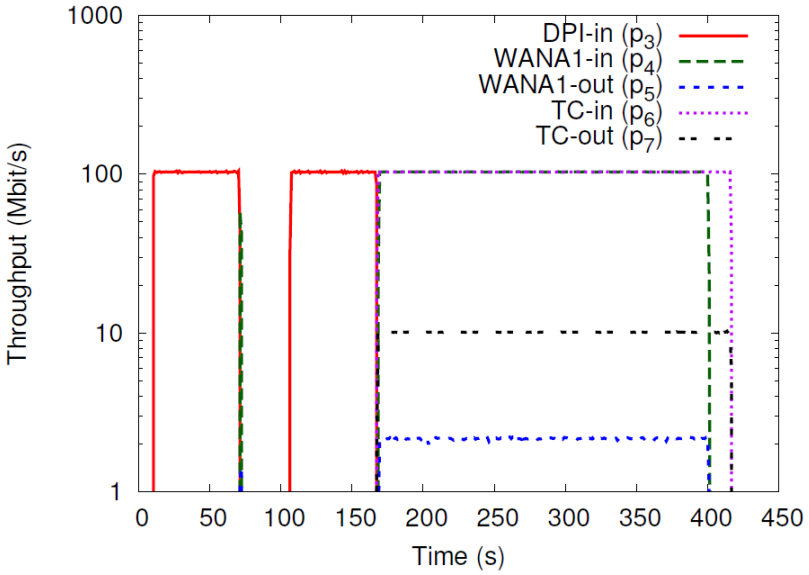


- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router

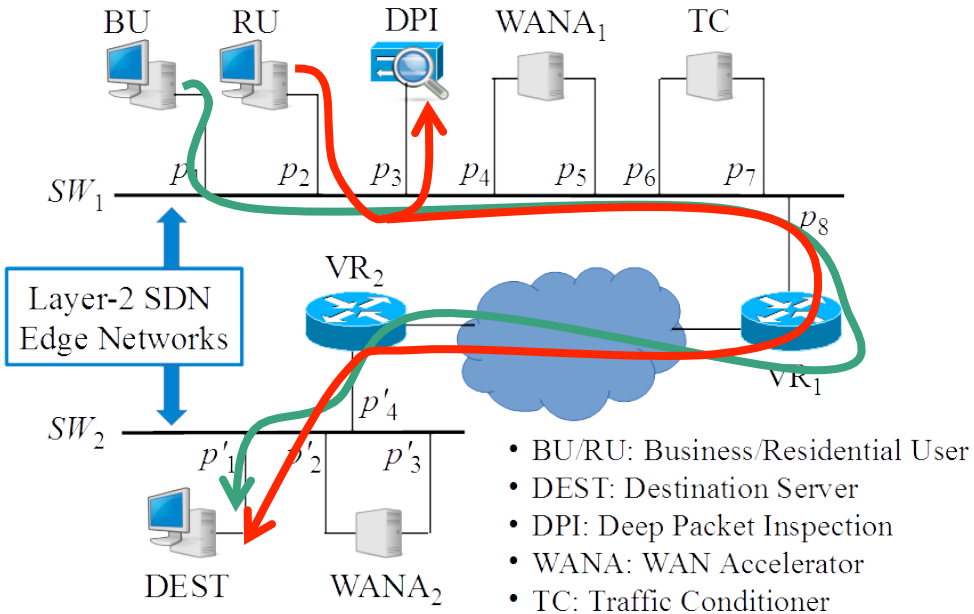
Phase 3: no congestion → SLA not enforced

Rules installed in SW1:

- Traffic from to DEST is forwarded directly to VR1
- Similarly for inbound packets



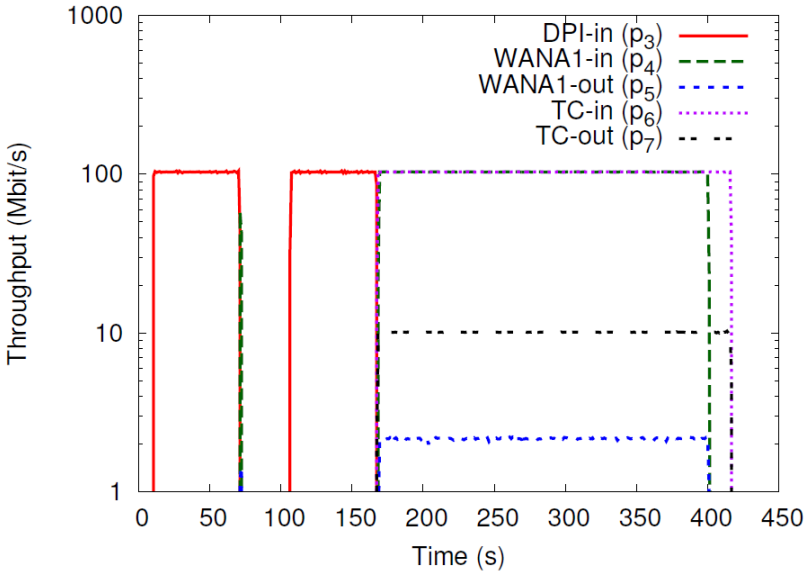
Proof of concept: SDN controller design



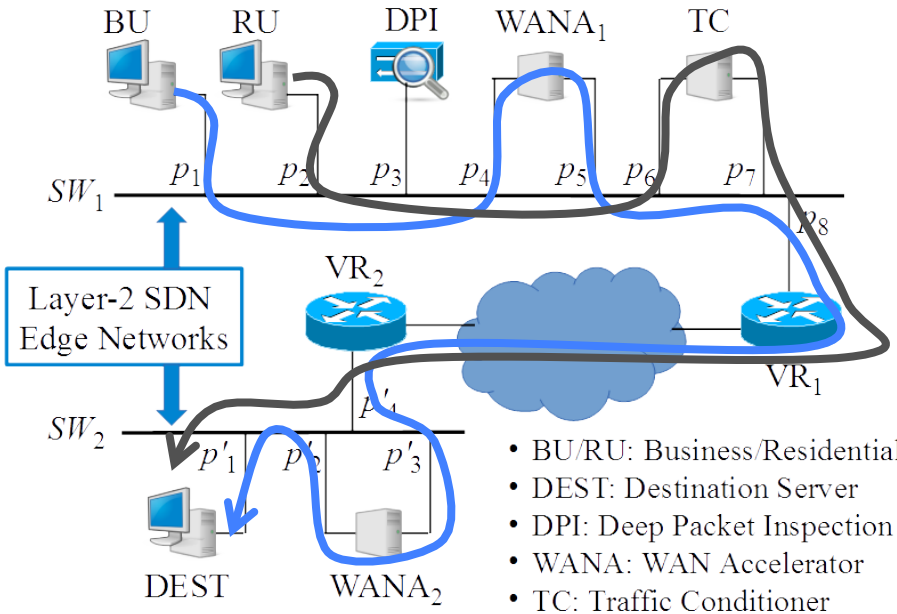
Phase 4: classification

Rules installed in SW1:

- Traffic from BU to DEST is forwarded directly to VR1
- Traffic from RU to DEST is forwarded both to VR1 and DPI
- Similarly for inbound packets



Proof of concept: SDN controller design

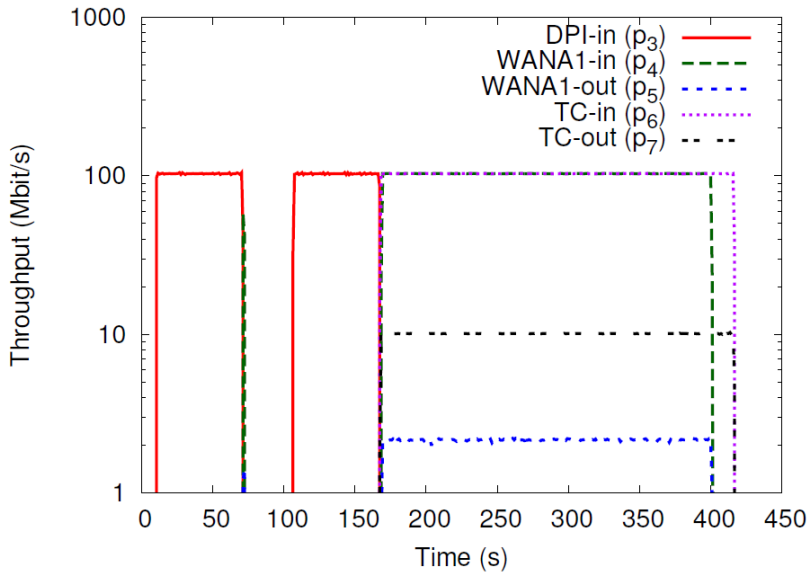


- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router

Phase 5: SLA compliance & congestion → SLA enforced

Rules installed in SW1:

- Traffic from to DEST is forwarded to VR1 via $WANA_1$
- Traffic from RU to DEST is forwarded to VR_1 via TC
- Similarly for inbound packets



Measurements

Flow	State transition	Time (s)
f_{BU}	$Init \rightarrow C$	10.62
	$C \rightarrow E$	71.36
	$E \rightarrow N$	73.46
	$N \rightarrow E$	168.43
	flow terminated	404.11
f_{RU}	$Init \rightarrow C$	106.45
	$C \rightarrow E$	167.36
	flow terminated	416.74

Indexes:

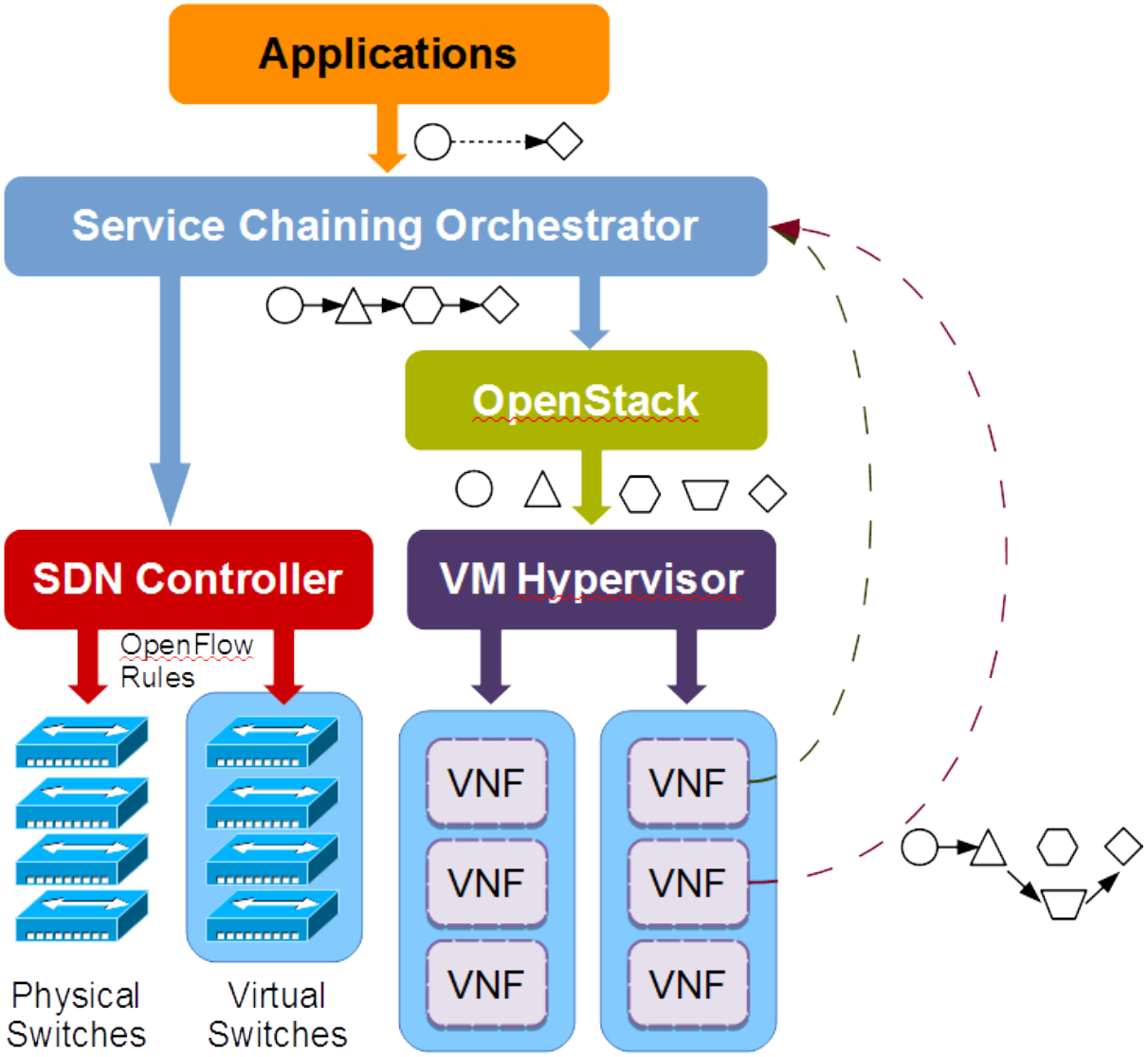
- RTT and Jitter experienced by UDP flows generated by RU
- Average obtained from 20 experiments
    - VNFs placed on the same server

	State	Max	Min	Average
RTT (ms)	C	14,840	1,525	3,972
	E	10,382	2,006	3,313
Jitter (ms)	C	0,322	0,080	0,125
	E	0,491	0,067	0,152

Conclusion

- Design methodology for a SDN Controller capable of steering traffic flows in a dynamic NFV environment
  - QoS enforcement in a multi-tenant cloud scenario
  - Proof-of-concept on the OpenStack platform
- General approach adopted
  - FSM able to capture sequence of operations that need to be execute on flows, regardless underlying network infrastructure
  - It can be further extended
- Towards a possible orchestration approach
  - Mutual dependence of different flows
  - Network resource contention

Functional architecture



THANKS FOR YOUR ATTENTION!

QUESTIONS?