Chair of Communication Networks
Department of Electrical and Computer Engineering
Technical University of Munich

Using Flexibility as a Measure to Evaluate Softwarized Networks

Wolfgang Kellerer

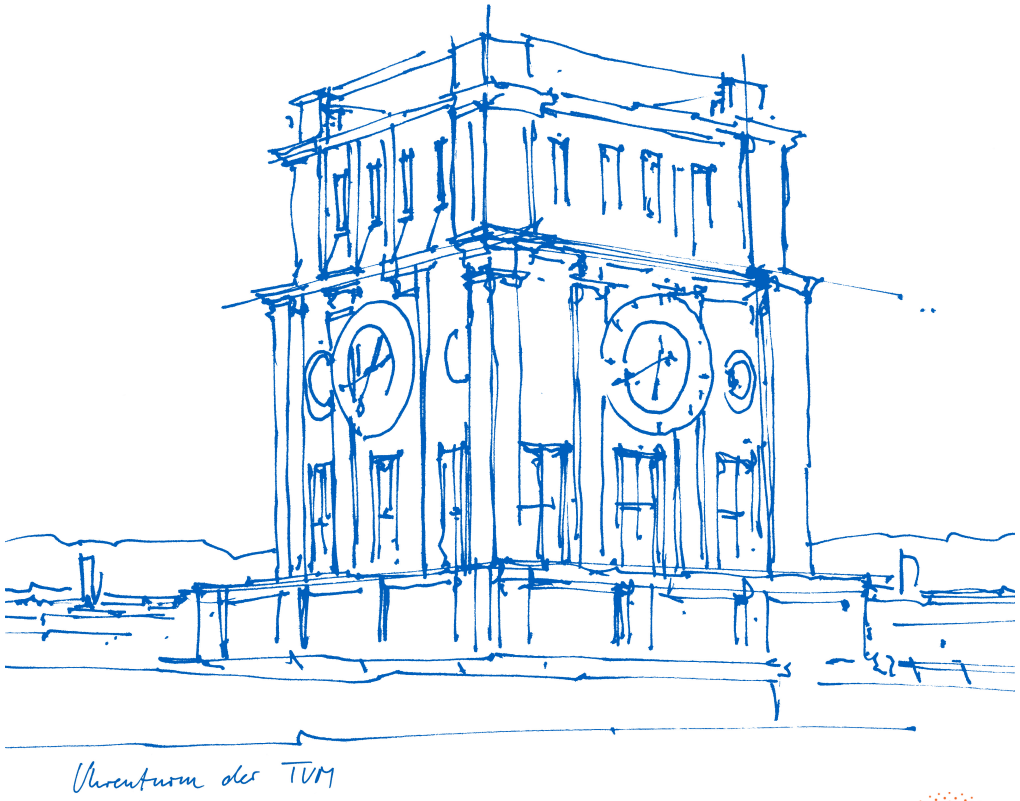
Technical University of Munich

Prague, July 17, 2017

IETF 99 Prague, Czech Republic

July 16-21, 2017

IRTF NFVRG



This work is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program grant agreement No 647158 – **FlexNets (2015 – 2020)**.

European Research Council
Established by the European Commission

Introduction

- Networking today: new requirements from vertical industries, dynamically changing user behavior, and global digitalization

- Less (explicitly) addressed: ***flexibility*** and hence ***adaptation***

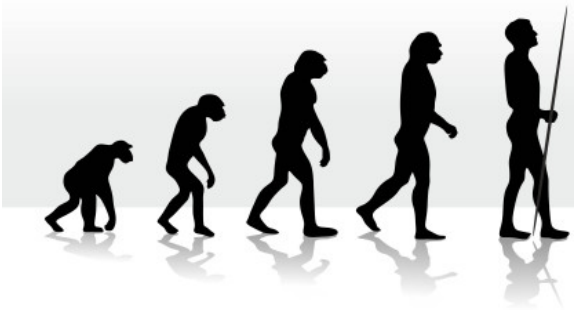


Image source: http://www.paleoplan.com

- In this talk, I will …
  … present our definition of a measure for network flexibility …
  … give concrete use cases of how to apply ..
  … raise more questions

FlexNets
2015 - 2020

erc
European Research Council
Established by the European Commission

The Internet

… is able to adapt its resources

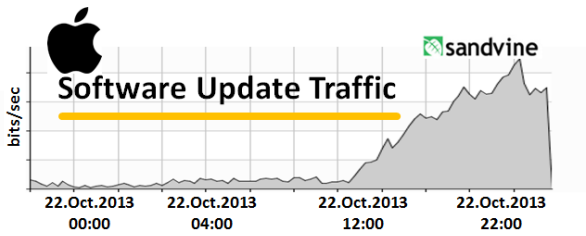
… *somehow* (best-effort, TCP elasticity, BGP, OSPF)

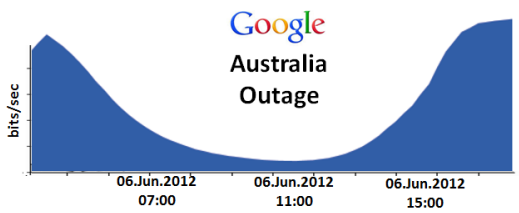
early-days simplicity

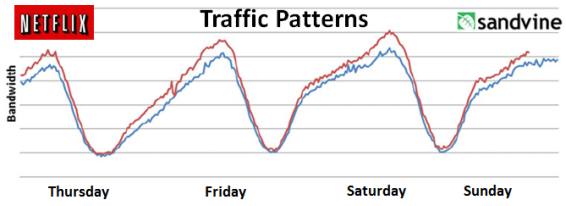
→ complex and ossified network system

very slow adaptation to new requirements

→ reaction to dynamic changes hardly possible



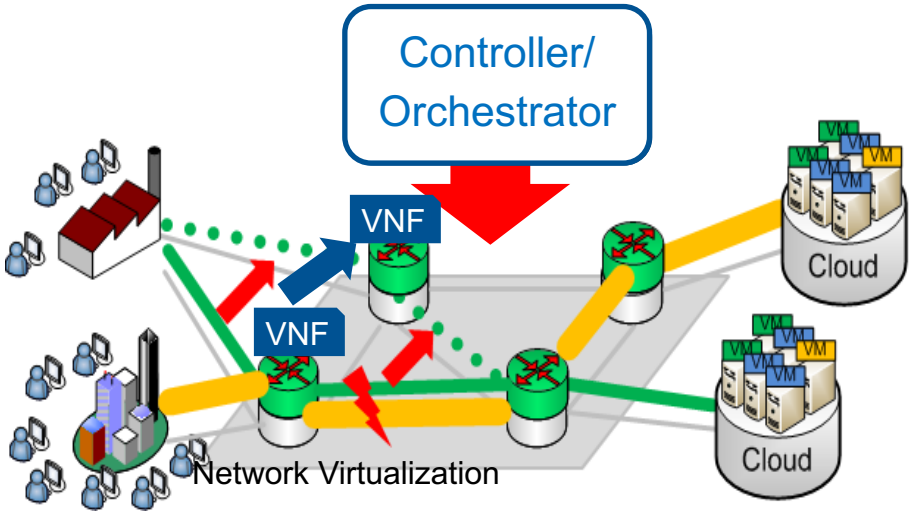


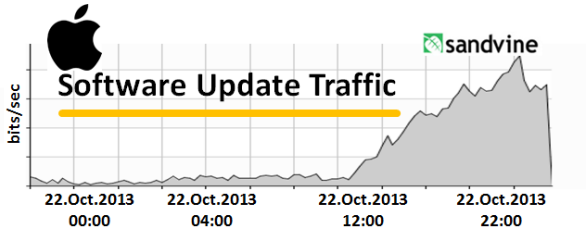


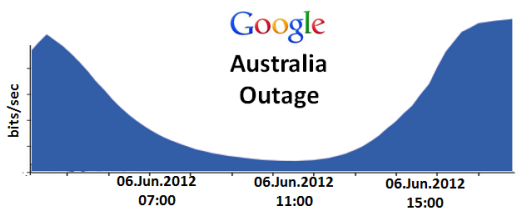
New concepts such as …

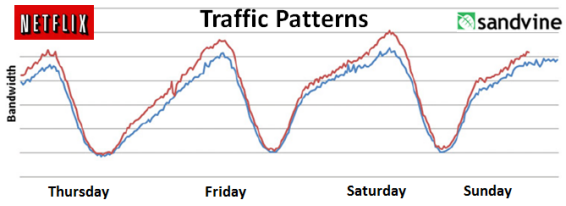
Network Function Virtualization (NFV) and Software Defined Networking (SDN)

…*promise* to create and adapt networks and functions on demand in software









All problems solved?

- Are we fully flexible already?
- How far can we go? What is the right network design?

We need
- a **fundamental understanding** of how to provide flexibility
- a **quantitative measure** for flexibility pro and contra certain designs

For networks, **flexibility** = ability to *support new requests* to change design requirements (traffic pattern, latencies,…) in a *timely* manner via adaptation of resources (topology, capacity, ...) if needed

This work is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 program grant agreement No 647158 – **FlexNets (2015 – 2020)**.

FlexNets
2015 - 2020

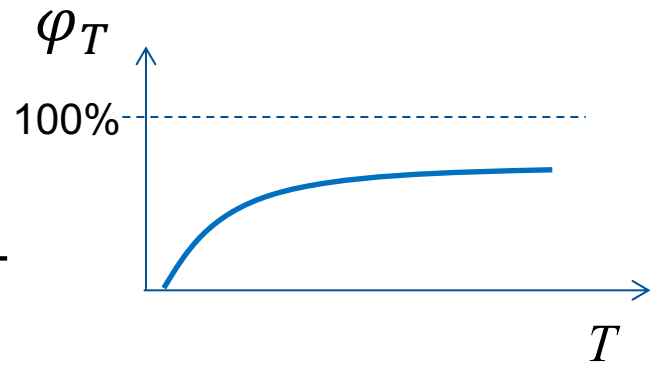
European Research Council

Flexibility Measure – proposed definition

$$\varphi_T \quad (S) = \frac{|supported\ new\ requests\ within\ T|}{|total\ number\ of\ given\ new\ requests|}$$

- fraction of the number of new requests that can be supported in a time interval T of all given new requests

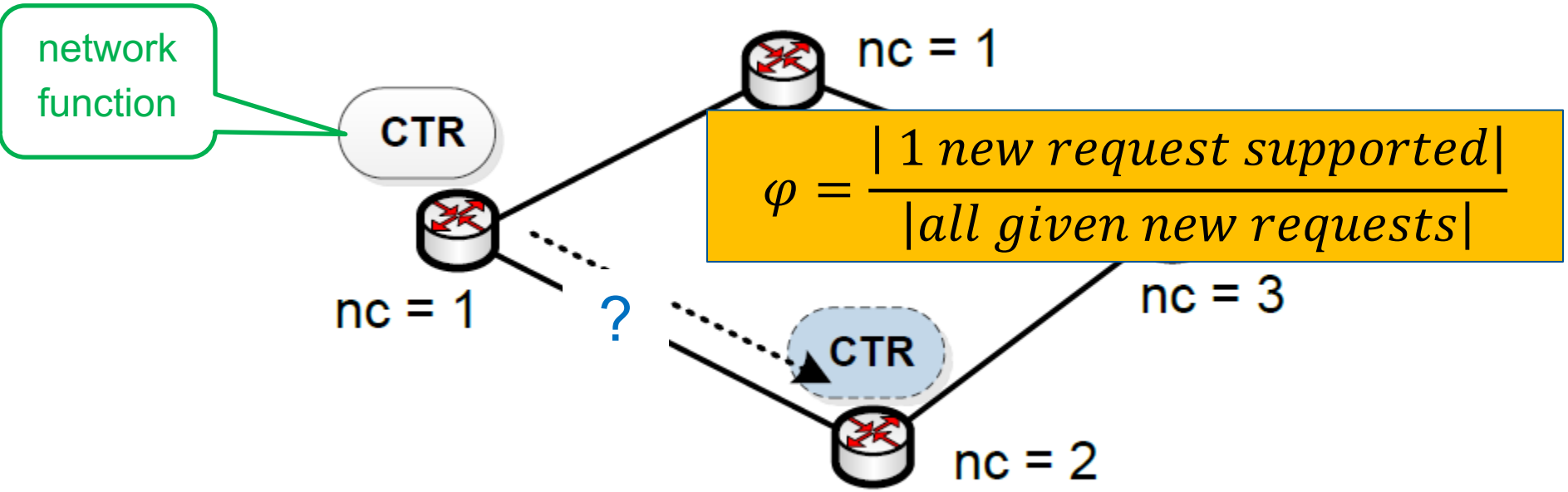
$$\varphi_{T->\infty} \quad (S) = \frac{|supported\ new\ requests|}{|all\ given\ new\ requests|}$$



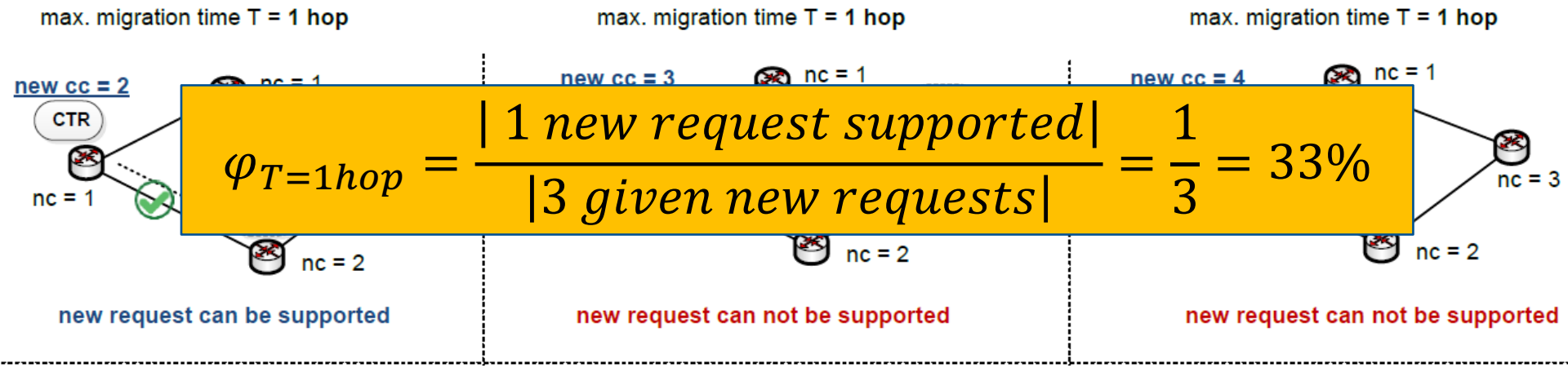
A simple illustration (1)

network function: SDN controller

- New request to an SDN-network: Controller Capacity (cc) is increased
- Can such new request be supported?
  e.g. by migrating the controller to a node with higher capacity (NC)
- BUT: migration time cannot exceed "1 hop" (T)



A simple illustration (2): more requests



$$\varphi_{T=1hop} = \frac{|\,1\ new\ request\ supported|}{|3\ given\ new\ requests|} = \frac{1}{3} = 33\%$$

Flexibility a new measure? - Yes

no single quality indicator for a ***Quality of Flexibilty (QoF)***

- similar to QoS
- to be regarded by case (requirements, design goals, system)

we propose: ***flexibility aspects*** [1, 2]

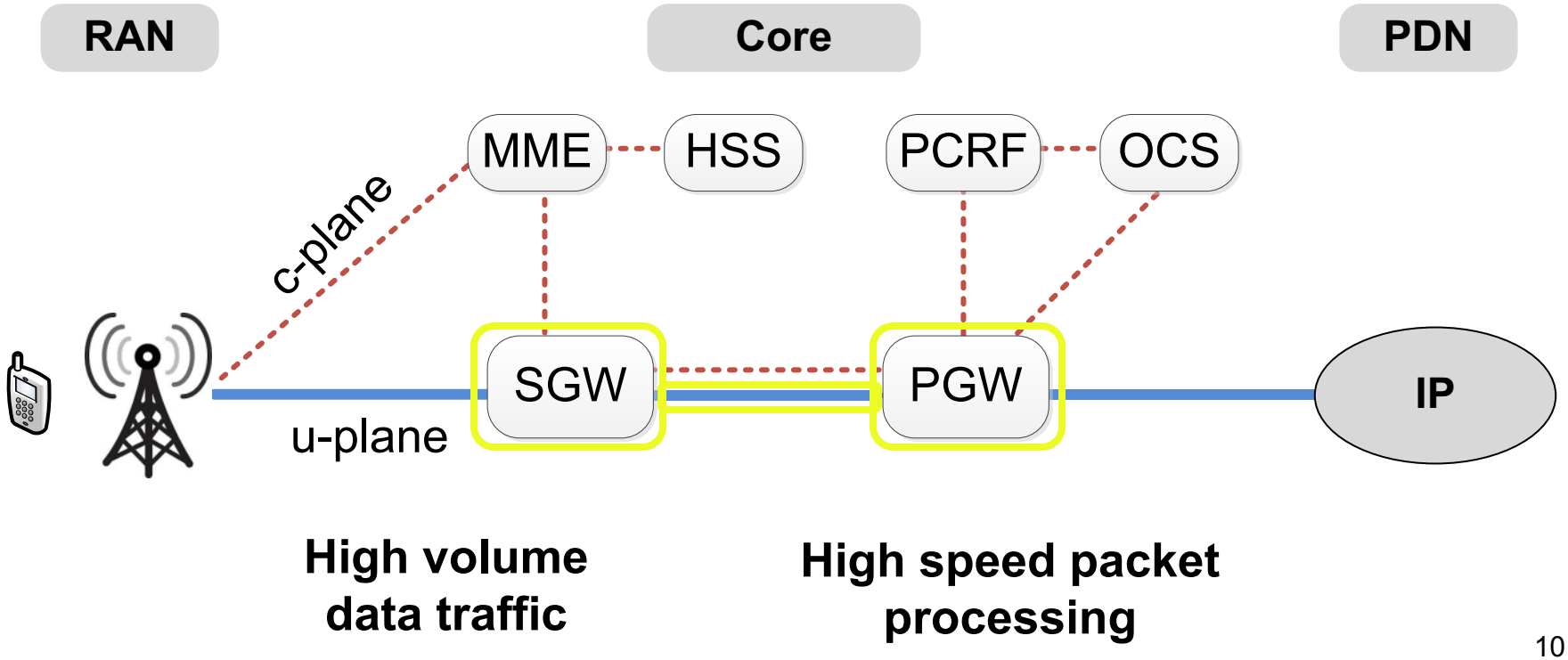
- similar as we do with QoS (rate, delay, throughput, jitter,…)
- shall allow us to quantitatively compare two different system designs
- Examples: *flow steering, function placement*

[1] W. Kellerer, A. Basta, A. Blenk, Using a Flexibility Measure for Network Design Space Analysis of SDN and NFV, SWFAN'16, IEEE INFOCOM Workshop, April 2016.
[2] W. Kellerer, A. Basta, A. Blenk, Flexibility of Networks: a new measure for network design space analysis?. arXiv preprint arXiv:1512.03770, 2015.

Use Case 1: *The Function Placement Problem*

- NFV = virtualize & move function (= everything) to DC

Example: mobile core network functions



Function Realization based on NFV

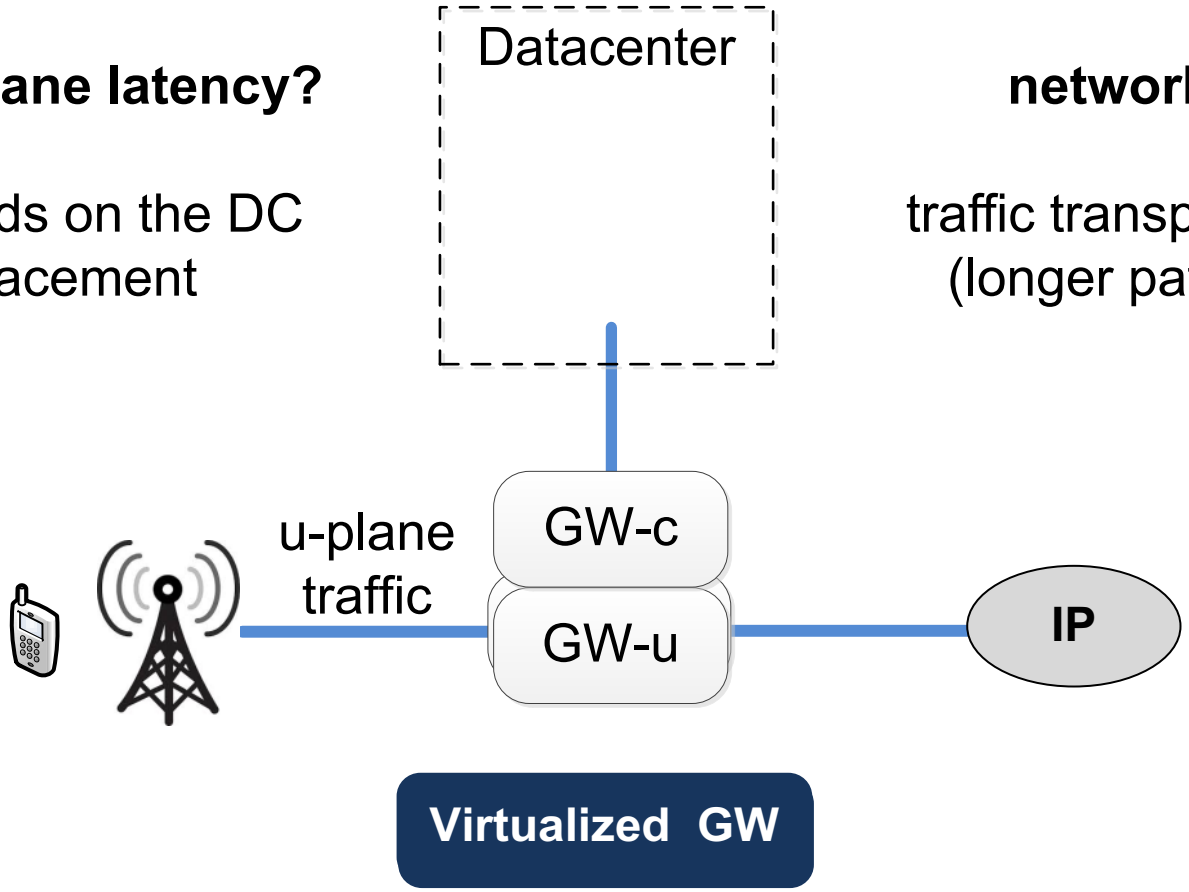
- Virtualization of GW functions [3] → NFV

data-plane latency?

depends on the DC placement

network load?

traffic transported to DC (longer path → cost)



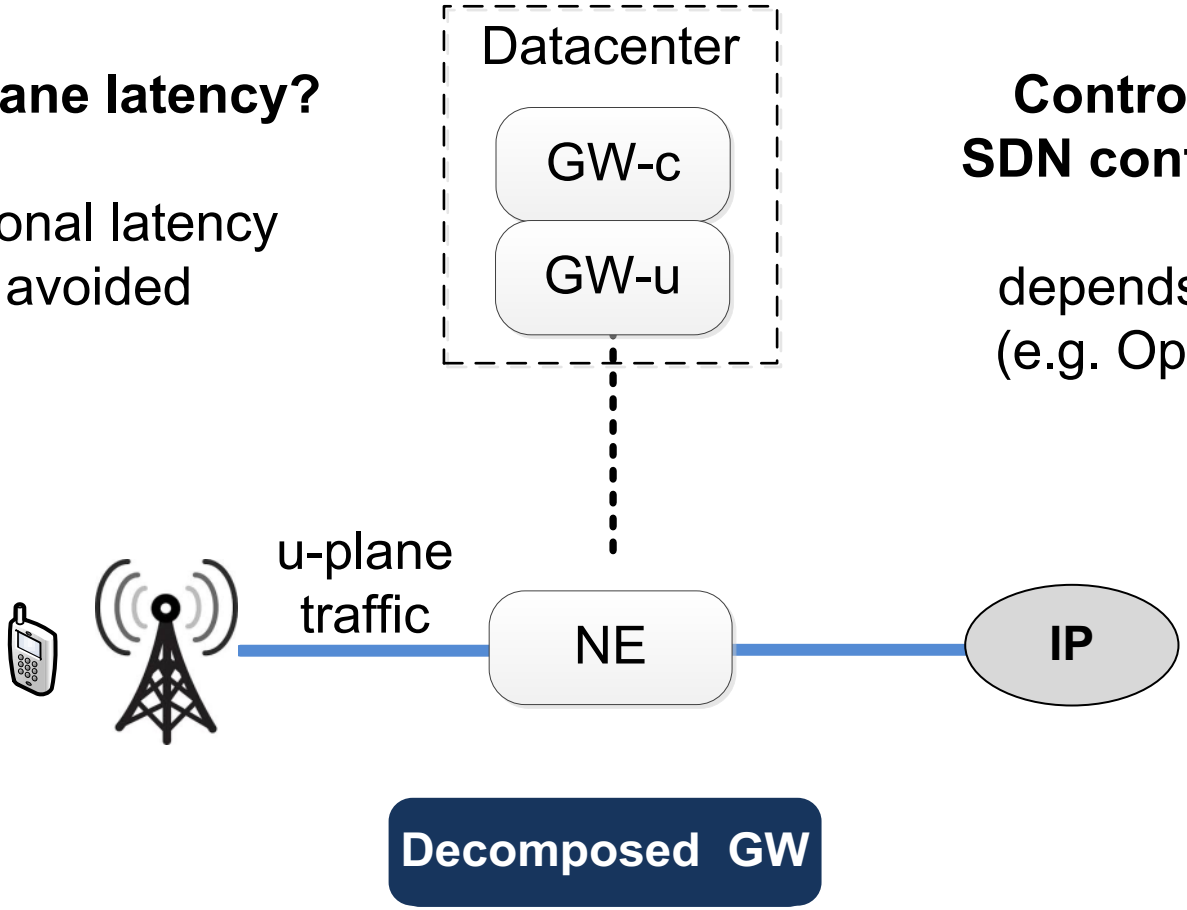
[3] A. Basta et al., A Virtual SDN-enabled EPC Architecture : a case study for S-/P-Gateways functions, SDN4FNS 2013.

Function Realization based on SDN: *move functions back*

- Decomposition of GW functions [3] via SDN

data-plane latency?

additional latency
is avoided



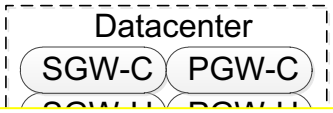
Control load?
SDN control load!

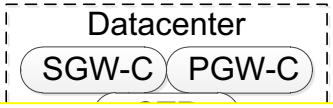
depends on API
(e.g. OpenFlow)

[3] A. Basta et al., A Virtual SDN-enabled EPC Architecture : a case study for S-/P-Gateways functions, SDN4FNS 2013.

Interdependencies → Function chains (mixed design)

- Propagation latency depends on function chain = path SGW - PGW





Can be more complex for other use cases

Function Placement shall address:

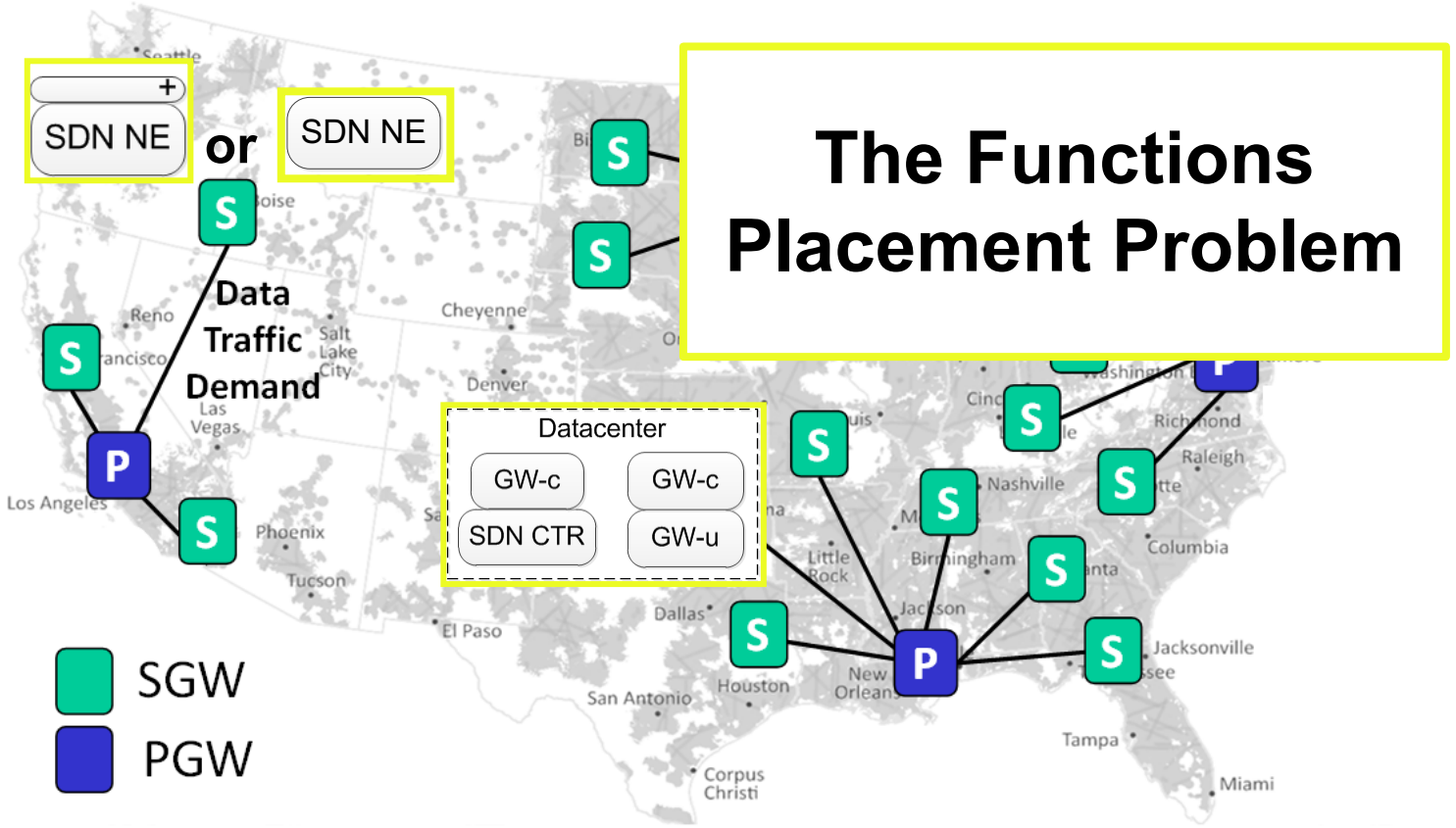
- **Function (de-)composition**
- **Function chaining**

(c) SGW Virtualized PGW Decomposed

(d) PGW Virtualized SGW Decomposed

Some Evaluation Studies [4]

- Virtualize all GWs? decompose all? mixed deployment?
  - Which GWs should be virtualized? decomposed? DC(s) placement?
    - minimize core load $
    - satisfy data-plane latency ✓



[4] A. Basta, W. Kellerer, M. Hoffmann, H. Morper, K. Hoffmann, Applying NFV and SDN to LTE Mobile Core Gateways; The Functions Placement Problem, AllThingsCellular14, Workshop ACM SICGOMM, Chicago, IL, USA, August 2014

Flexibility Analysis of Function Placement

Use Case 1

3 design choices (= systems) to compare [1]:

(1) SDN design

(2) NFV design

(3) mixed SDN/NFV design

Parameter in focus:

- Flexibility to support different latency requirements for
  - control plane latency and data plane latency

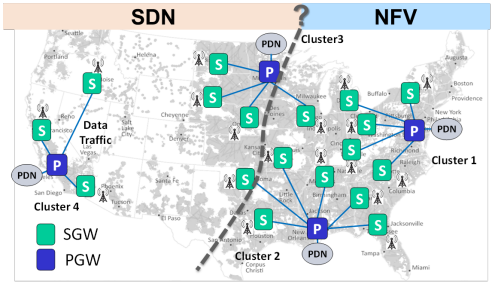
    e.g.: {5, 10, 15,…, 45, 50} ms

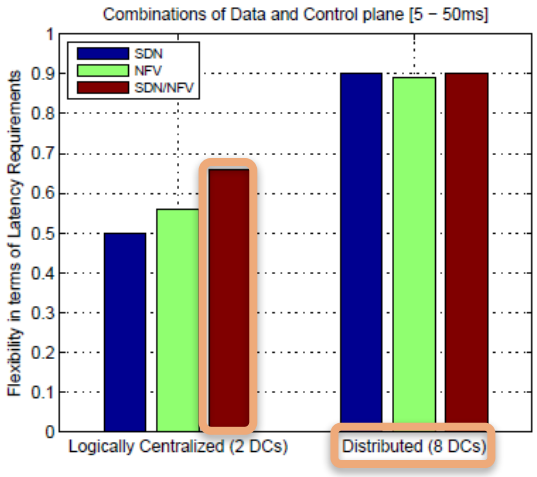
all requests:
10 x10 =100

$$\varphi^{placement}(design.x) = \frac{\left(\sum_i \sum_j feasibleSol_{i,j} \cdot w_{i,j}\right)}{\sum_i \sum_j w_{i,j}}$$

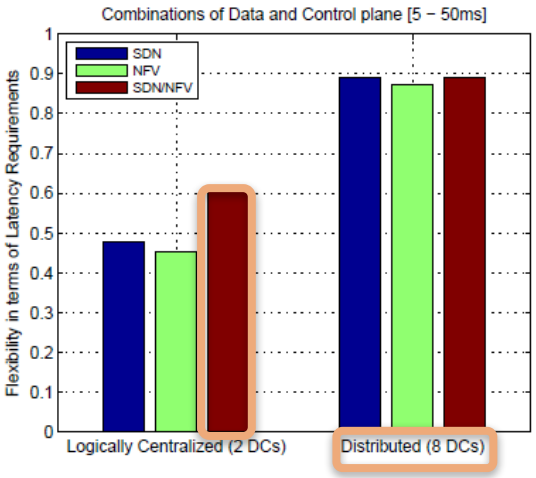
[1] W. Kellerer, A. Basta, A. Blenk,
Using a Flexibility Measure for Network Design Space Analysis of SDN and NFV, SWFAN'16,
IEEE INFOCOM Workshop, April 2016.

Results [1]

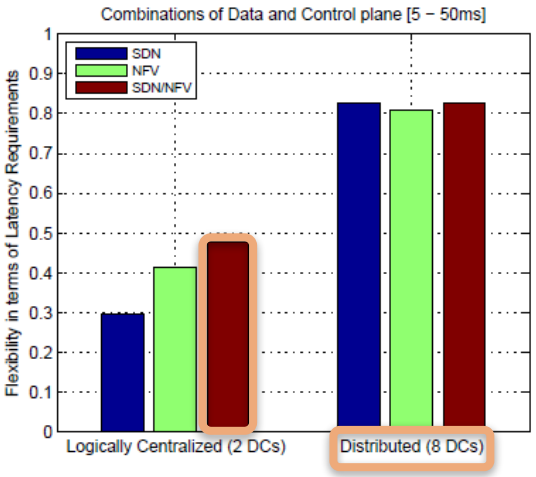




(a) equal weights for data and control latencies



(b) weights biased by data latency



(c) weights biased by control latency

With respect to the support of latency requirements in function placement:

- mixed SDN/NFV is more flexible for a logically centralized data center infrastructure
- for distributed data centers all three design choices are equally flexible

[1] W. Kellerer, A. Basta, A. Blenk, Using a Flexibility Measure for Network Design Space Analysis of SDN and NFV, SWFAN'16, IEEE INFOCOM Workshop, April 2016.

Use Case 2: Dynamic Controller Placement Problem

SDN controller as the network function

- place 1 ..n SDN controllers for time varying traffic input
  → controller migration/reconfiguration

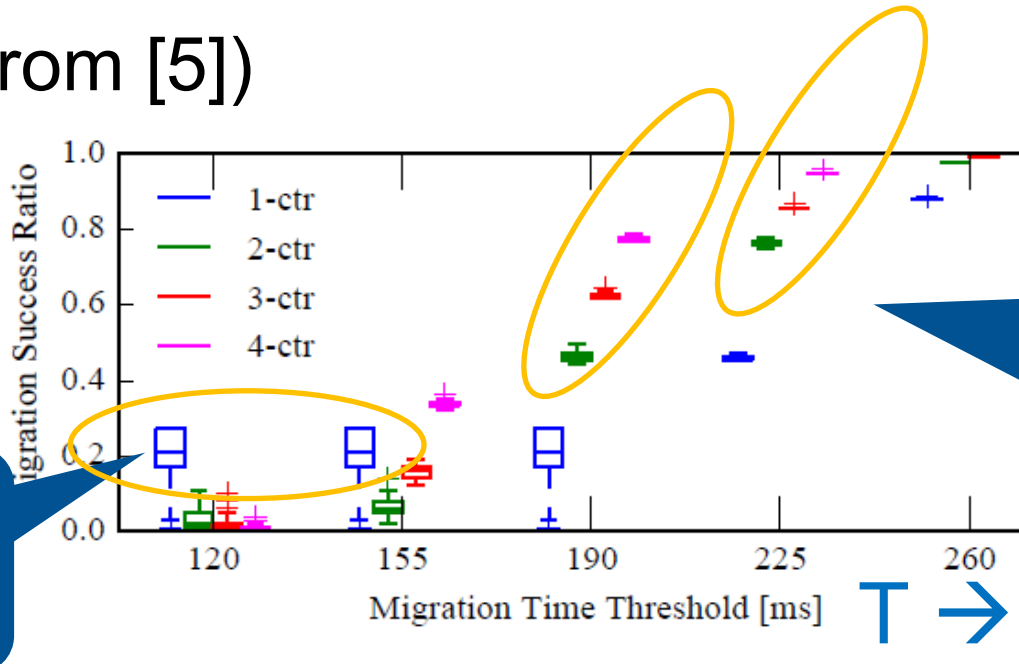
- Evaluation parameters [5, 6]
  - Abilene network topology (11 nodes, 14 links)
  - new requests: 100 different flow profile requests over time (random)
  - N = 1,…, 4 controllers (design choices for comparison)
  - Algorithm finds optimal controller placement and flow to controller assignment
    optimization goal: minimize avg. flow setup time (**performance**)
  - How many controllers can be migrated (incl. control plane update) in time T?
    (success ratio → **Flexibility**)
  - Migrations and reconfigurations → **Cost**

[5] M. He, A. Basta, A. Blenk, W. Kellerer, *How Flexible is Dynamic SDN Control Plane?,*
IEEE INFOCOM Workshop, SWFAN, Atlanta, USA, May 2017.

[6] M. He, A. Basta, A. Blenk, W. Kellerer, *Modeling Flow Setup Time for Controller Placement in SDN: Evaluation for Dynamic Flows,*
IEEE International Conference on Communications (ICC), Paris, France, May 2017.

Results (from [5])

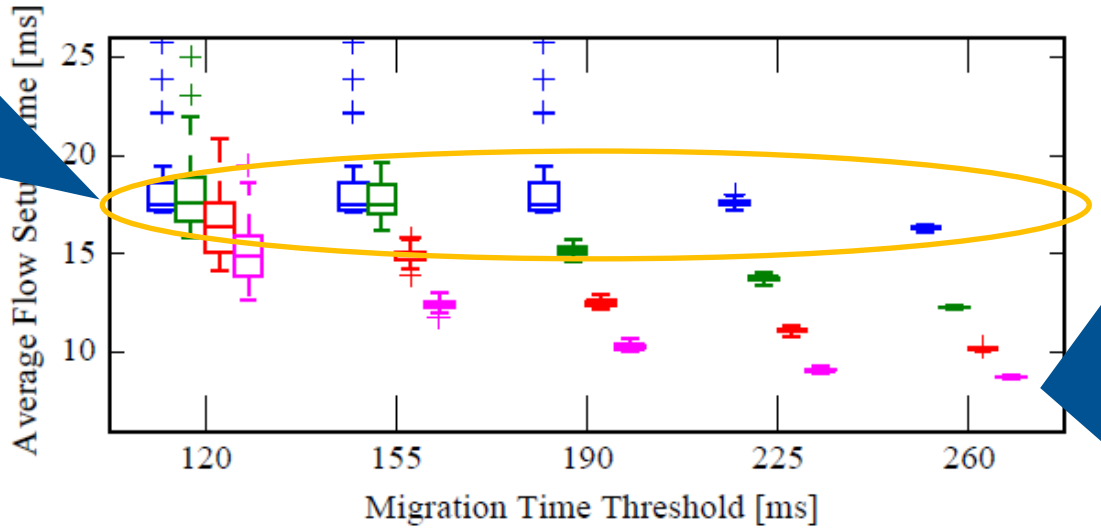
Flexibility



(a) Abilene, Flexibility Measure

for short T: 1 controller is more flexible

T considerable for migration: more controllers → more flexibility



performance of 1 controller system is worst

there is a cap in gain (flexibility and performance), but *cost* (= migrations) is rising (not shown here)

Performance

(low is better)

[5] M. He, A. Basta, A. Blenk, W. Kellerer, *How Flexible is Dynamic SDN Control Plane?,* IEEE INFOCOM Workshop, SWFAN, Atlanta, USA, May 2017.

Conclusion & Outlook

Key Takeaways

- Network research is faced with new requirements from emerging networked industries
- These include **flexibility**

- Network softwarization (NFV, SDN) is a key technology

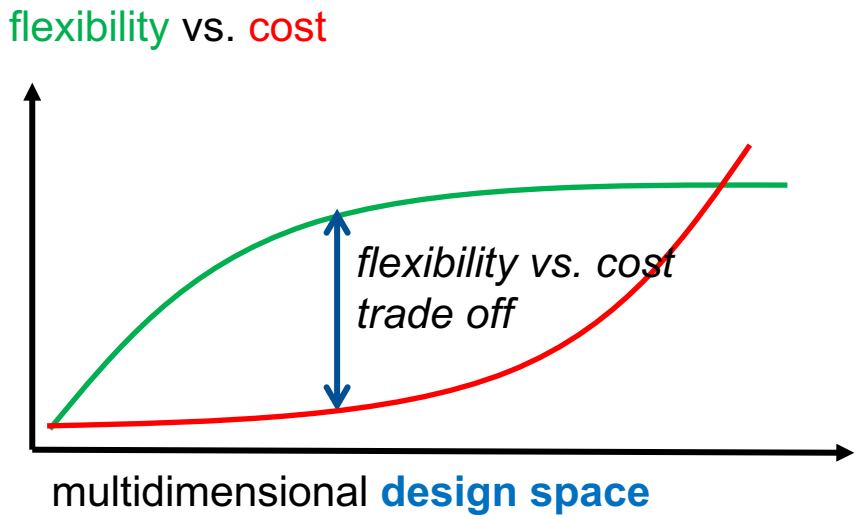
- Need for
  - a **measure** to analyse flexibility
  - as a trade off with performance and cost

Outlook: Cost of Flexibility

What are the costs of a design for flexibility?

- in terms of signaling overhead, number of data centers,…

Possible relationship (to be confirmed):



References for further reading (1)

- M. He, A. Basta, A. Blenk, W. Kellerer, *How Flexible is Dynamic SDN Control Plane?,* IEEE INFOCOM Workshop, SWFAN, Atlanta, USA, May 2017.

- M. He, A. Basta, A. Blenk, W. Kellerer, *Modeling Flow Setup Time for Controller Placement in SDN: Evaluation for Dynamic Flows,* IEEE International Conference on Communications (ICC), Paris, France, May 2017.

- W. Kellerer, A. Basta, A. Blenk, *Using a Flexibility Measure for Network Design Space Analysis of SDN and NFV,* IEEE INFOCOM Workshop, SWFAN, San Francisco, USA, April 2016.

- A. Basta, W. Kellerer, M. Hoffmann, H. Morper, K. Hoffmann, *Applying NFV and SDN to LTE Mobile Core Gateways; The Functions Placement Problem*, AllThingsCellular14, Workshop ACM SICGOMM, Chicago, IL, USA, August 2014.

- A. Basta, A. Blenk, M. Hoffmann, H. Morper, K. Hoffmann, W. Kellerer, *SDN and NFV Dynamic Operation of LTE EPC Gateways for Time-varying Traffic Patterns,* 6th International Conference on Mobile Networks and Management (MONAMI), Würzburg, Germany, September 2014.

- W. Kellerer, A. Basta, A. Blenk, *Flexibility of Networks: a new measure for network design space analysis?,* arXive report, December 2015. http://www.lkn.ei.tum.de/forschung/publikationen/dateien/Kellerer2015FlexibilityofNetworks:a.pdf

References for further reading (2)

- A. Basta et al., A Virtual SDN-enabled EPC Architecture : a case study for S-/P-Gateways functions, SDN4FNS 2013.

- A. Blenk, A. Basta, J. Zerwas, M. Reisslein, W. Kellerer, Control Plane Latency with SDN Network Hypervisors: Cost of Virtualization,
  IEEE Transactions on Network and Service Management, September 2016

- A. Blenk, A. Basta, M. Reisslein, W. Kellerer, Survey on Network Virtualization Hypervisors for Software Defined Networking,
  IEEE Communications Surveys & Tutorials, vol. 18, no. 1, pp. 655-685, January 2016.

- R. Sherwood et al., Carving research slices out of your production networks with OpenFlow, ACM CCR, 2010

- A. Al-Shabibi et al, OpenVirteX: A network hypervisor, Open Networking Summit, 2014

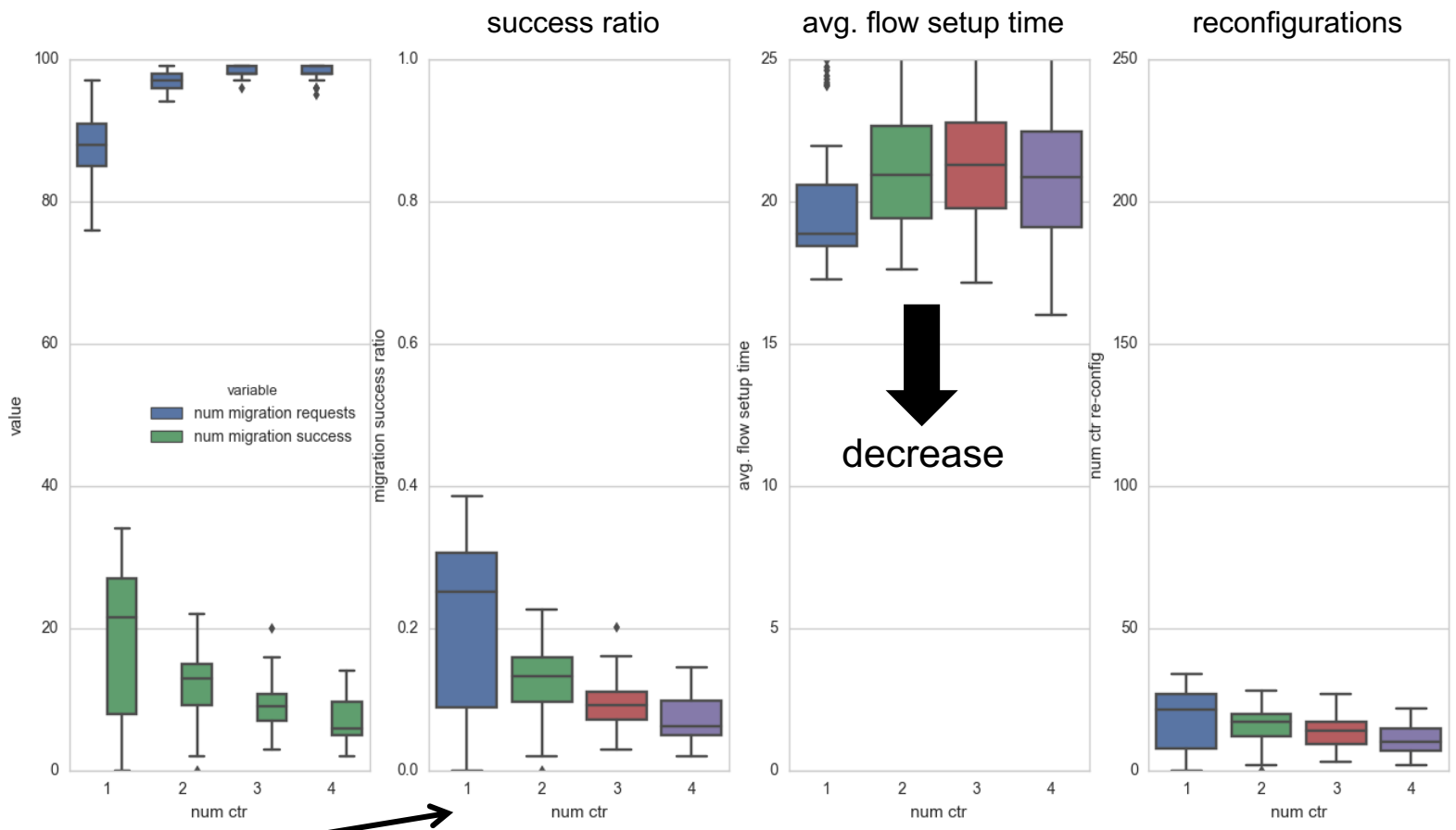
- 5G Initiative Team, NGMN 5G White Paper, 2015, https://www.ngmn.org/uploads/media/NGMN-5G-White-Paper-V1-0.pdf

- Mobile and wireless communications Enablers for the Twenty twenty Information Society (METIS), Final report on architecture
  (Deliverable D6.4), 2015, https://www.metis2020.com/wpcontent/uploads/deliverables/METIS-D6.4-v2.pdf

Simulation Results

Use Case

Flexibility **Performance** **Cost**



Number of controllers N

migration time threshold = 803 ms

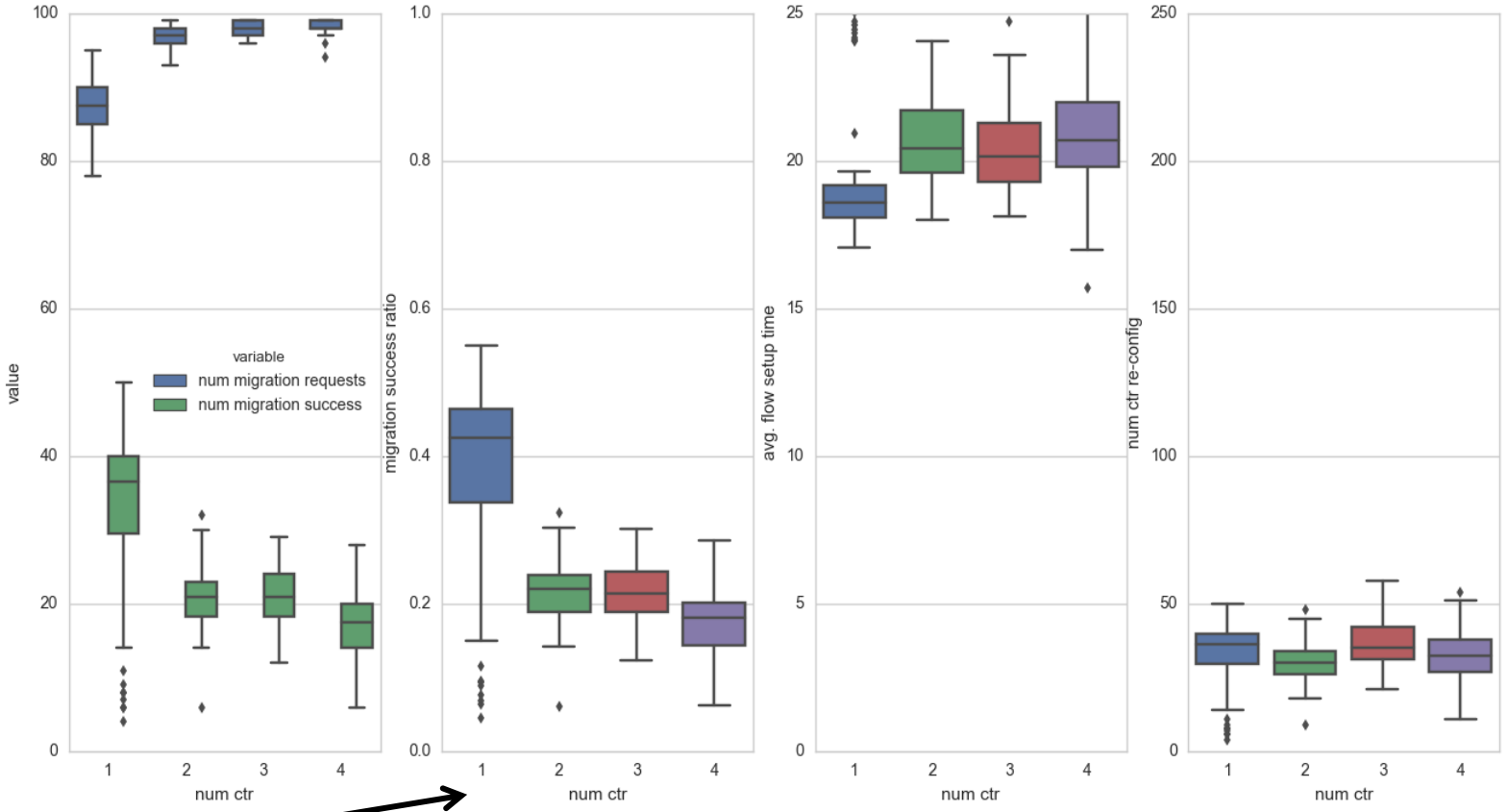
T is very short (800 ms is transmission delay of 1 controller)

Simulation Results

Use Case

Flexibility **Performance** **Cost**

success ratio avg. flow setup time reconfigurations



Number of controllers N

migration time threshold = 804 ms

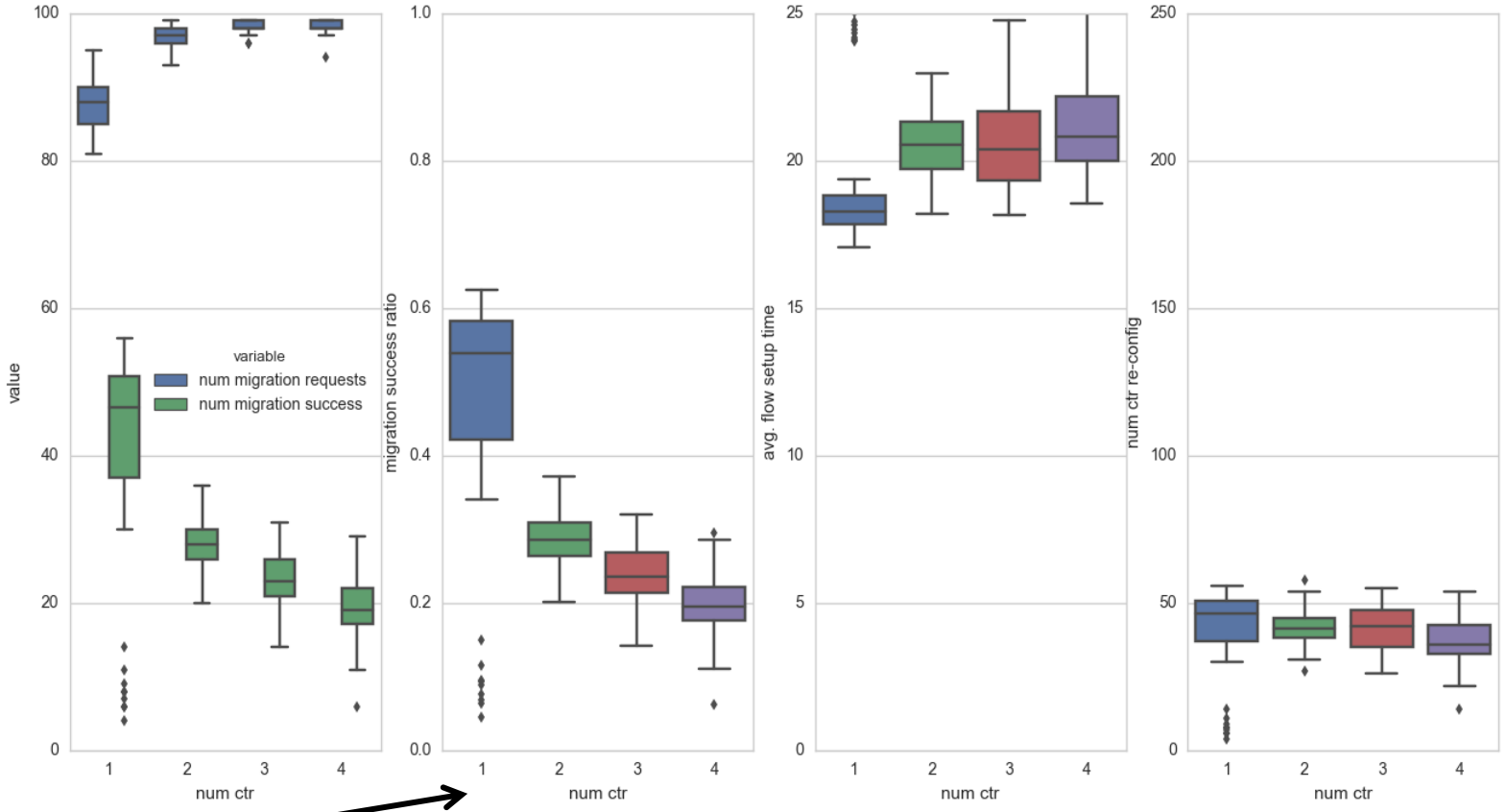
T is very short (800 ms is transmission delay)

Simulation Results

Use Case

Flexibility **Performance** **Cost**

success ratio avg. flow setup time reconfigurations



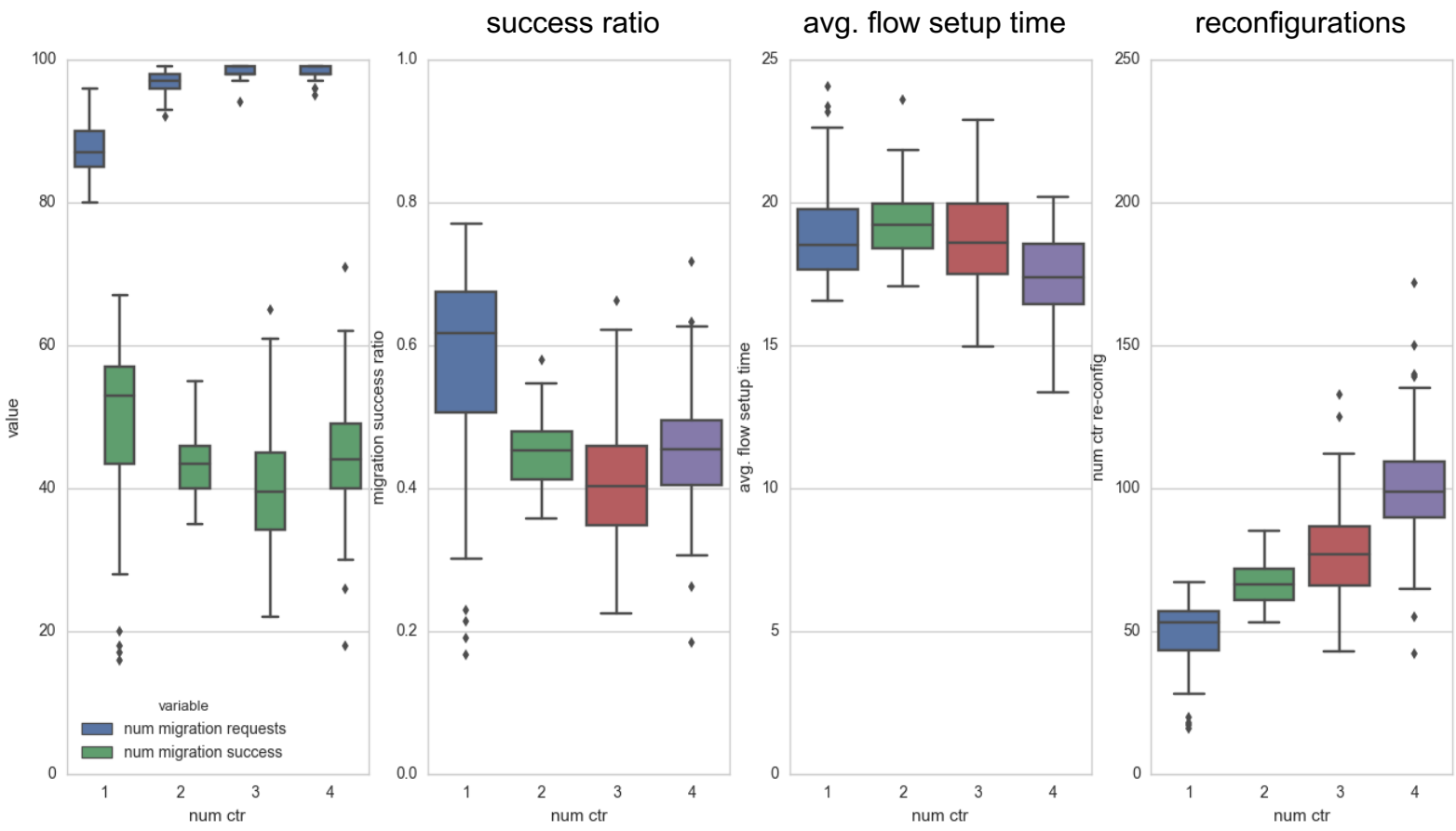
Number of controllers N

migration time threshold = 805 ms

Simulation Results

Use Case

Flexibility **Performance** **Cost**



migration time threshold = 806 ms

1 controller has highest flexibility at low cost

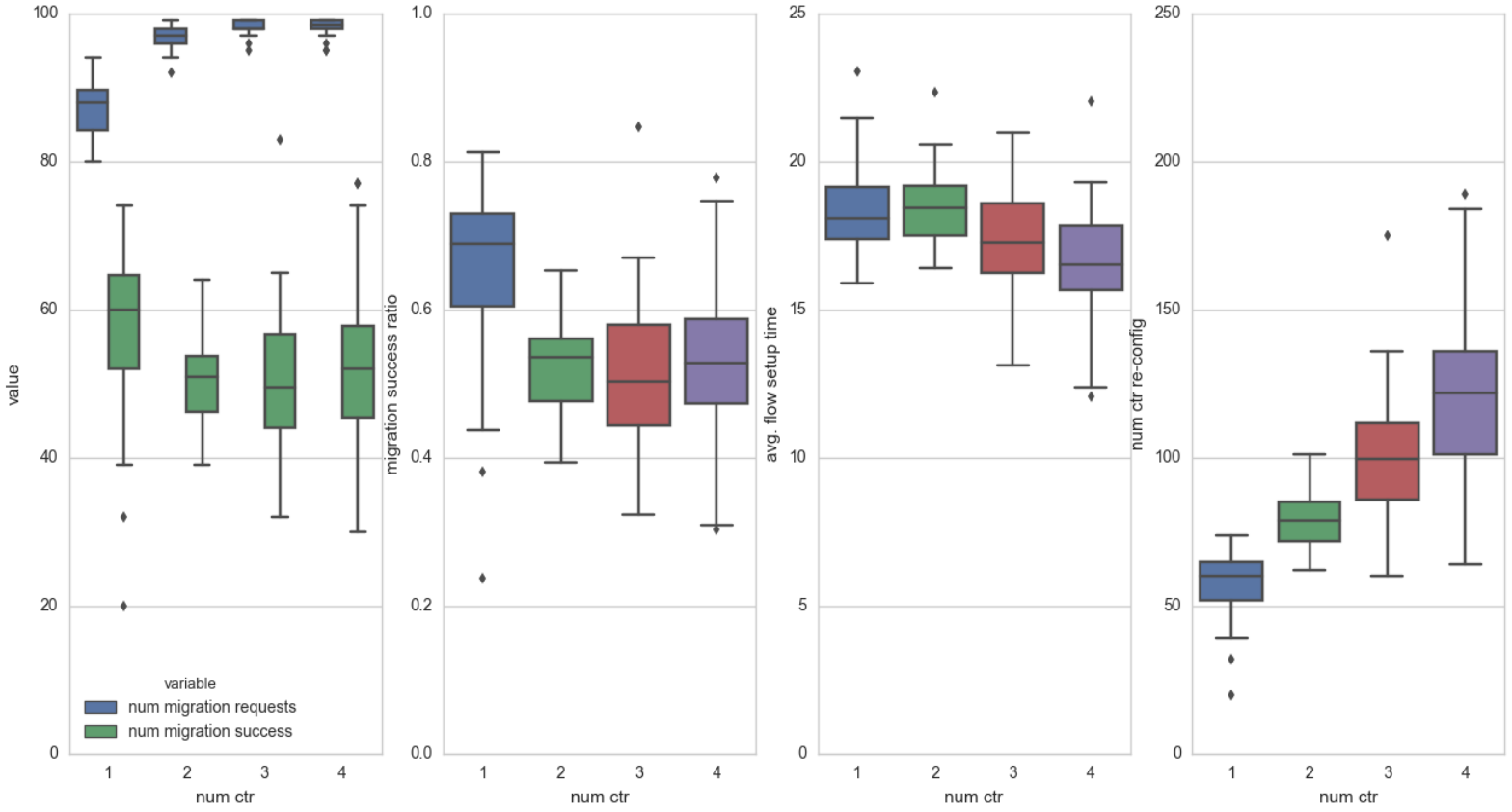
But: performance is not good (flow setup time)

Simulation Results

Use Case

Flexibility **Performance** **Cost**

success ratio avg. flow setup time reconfigurations

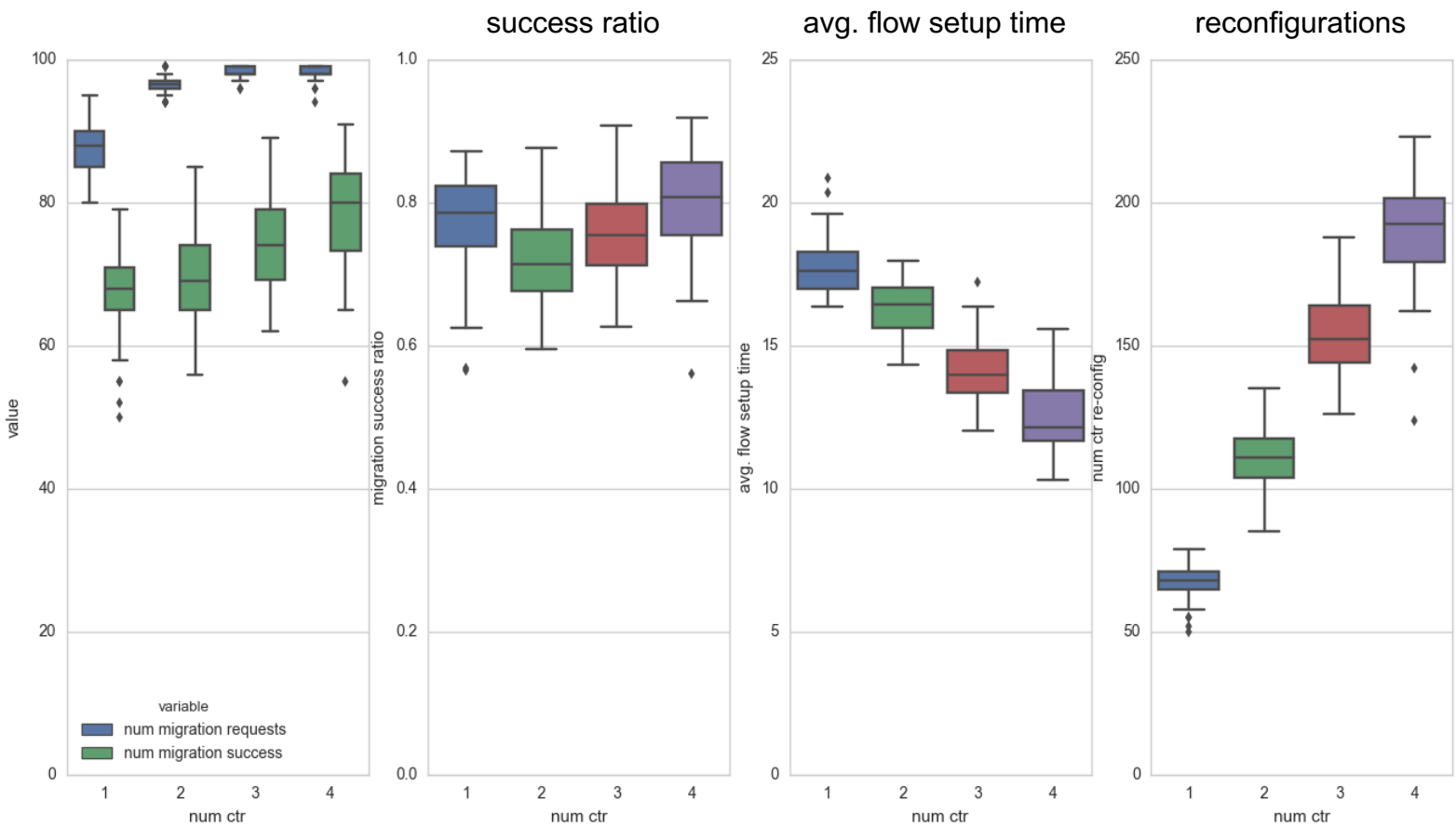


migration time threshold = 807 ms

Simulation Results

Use Case

Flexibility **Performance** **Cost**



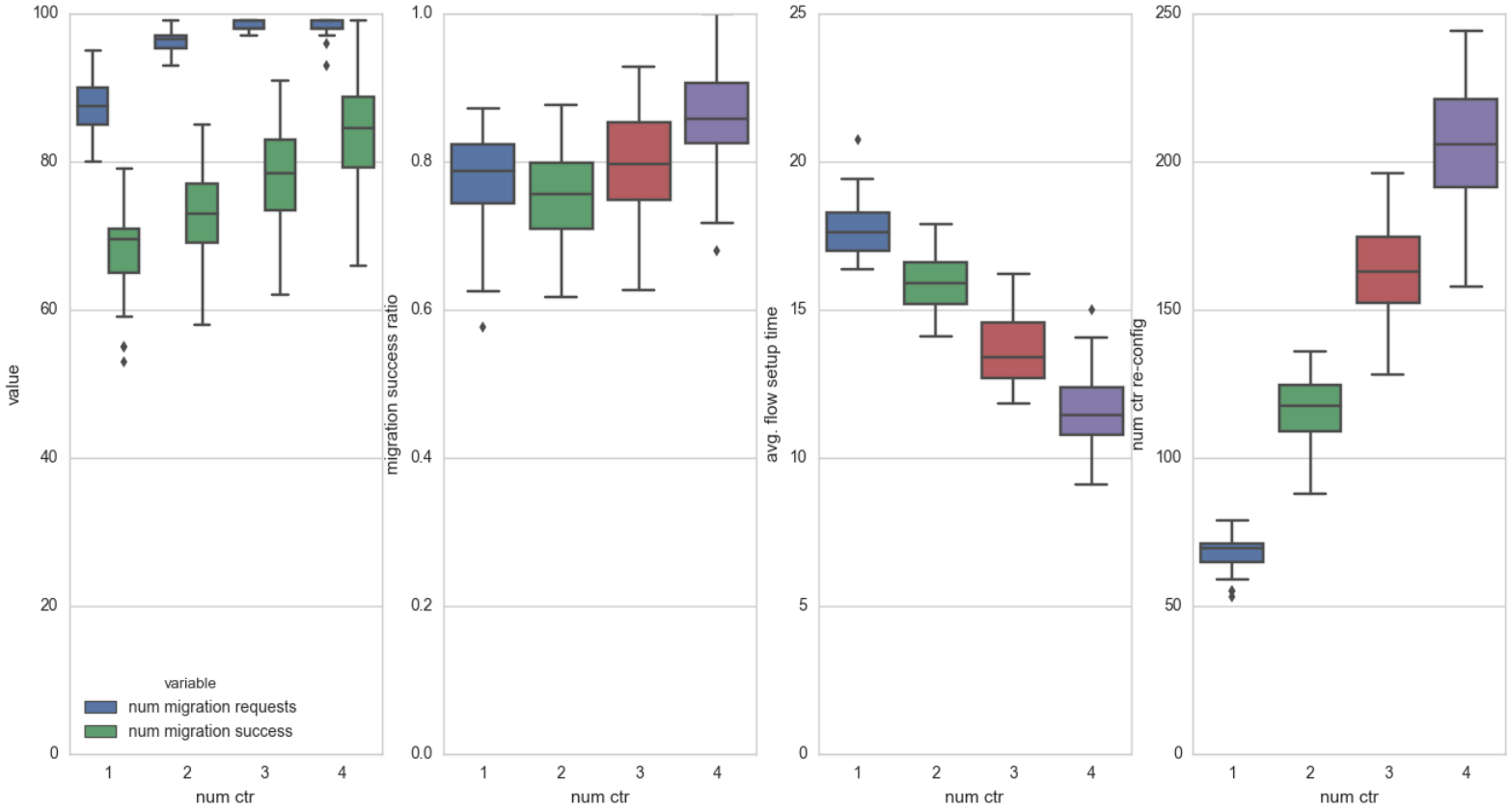
migration time threshold = 808 ms

Simulation Results

Use Case

Flexibility **Performance** **Cost**

success ratio avg. flow setup time reconfigurations



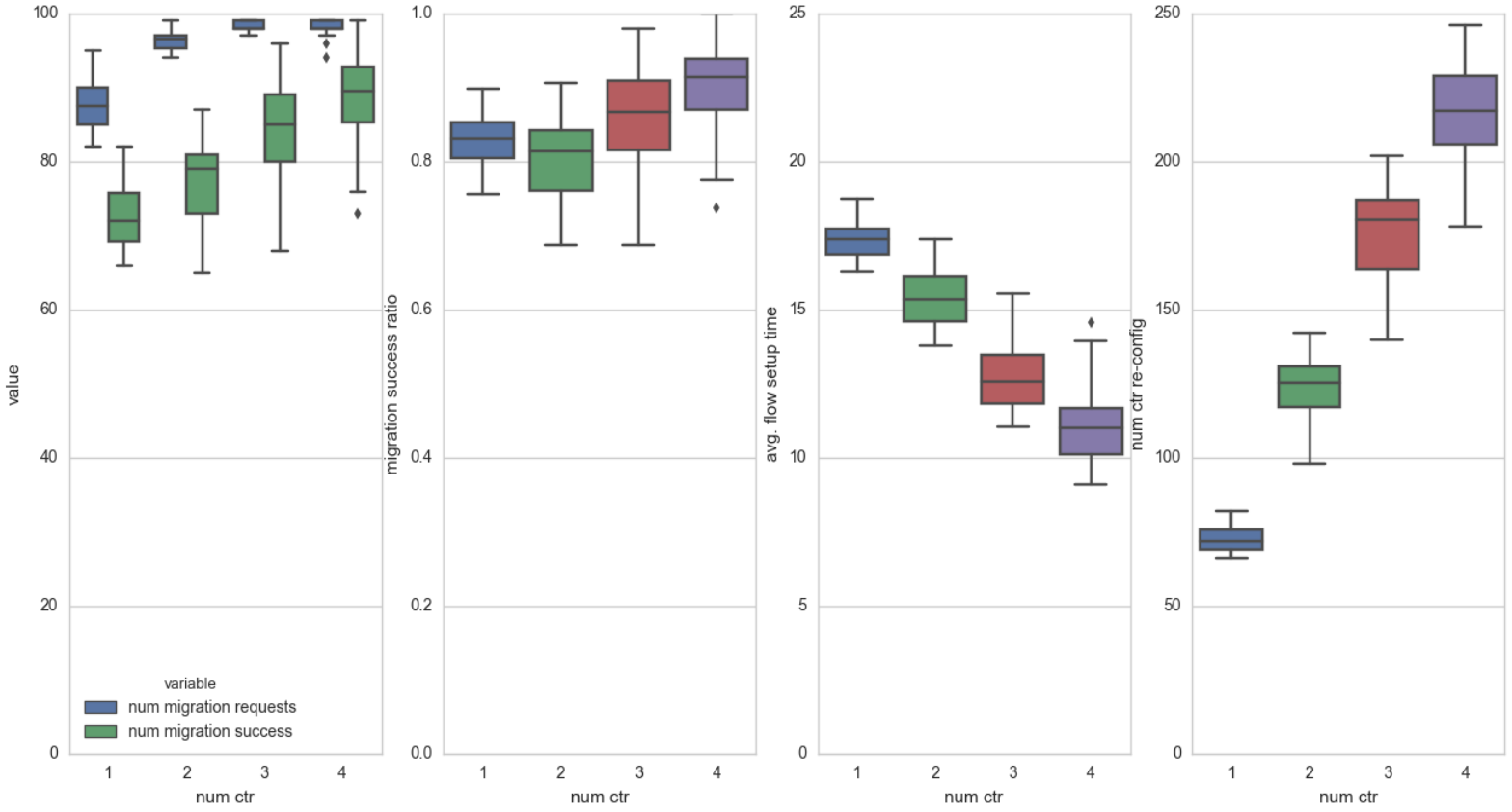
migration time threshold = 809 ms

Simulation Results

Use Case

Flexibility **Performance** **Cost**

success ratio avg. flow setup time reconfigurations



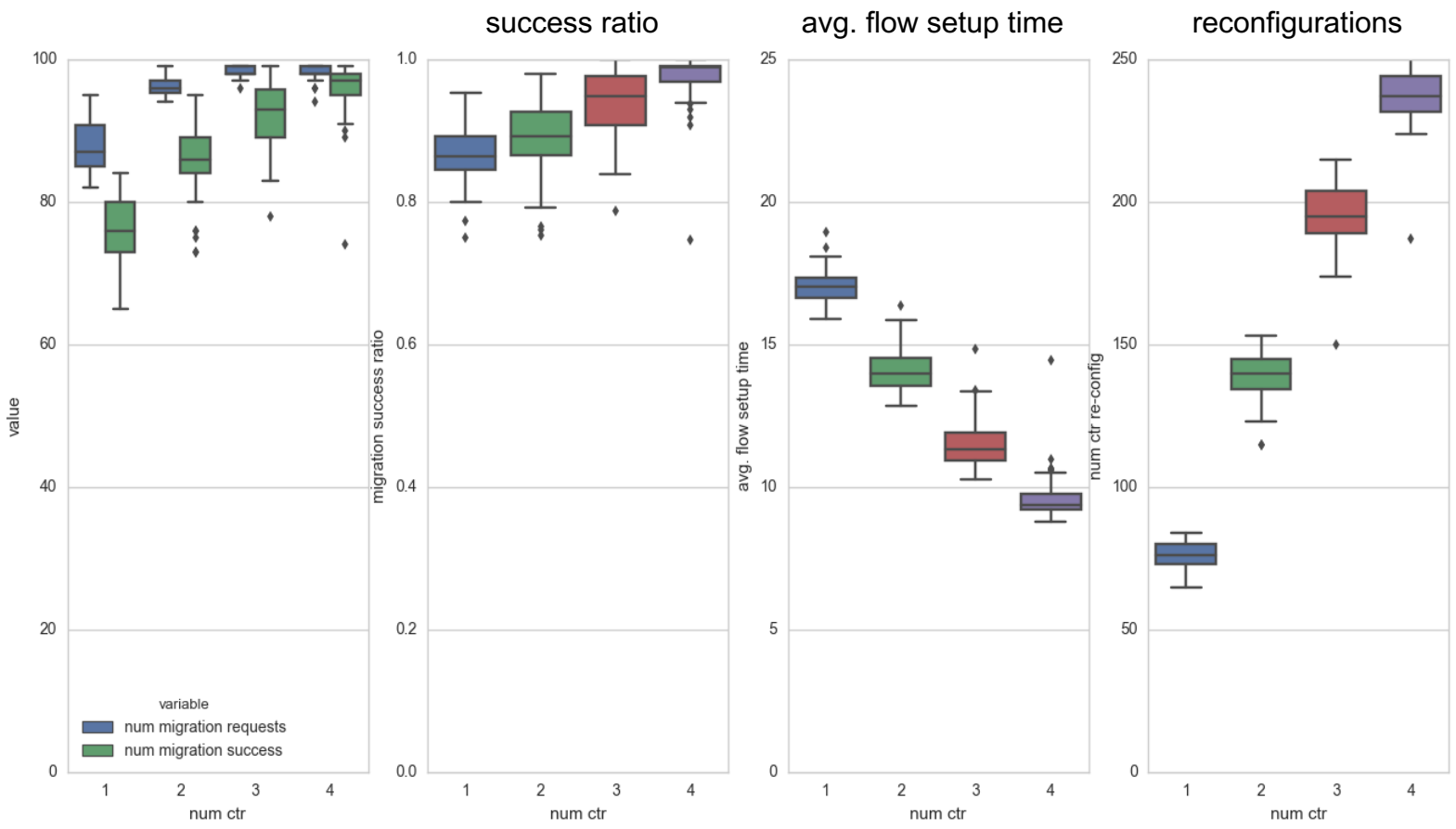
migration time threshold = 810 ms

T is moderate: more controllers → higher flexibility at higher cost

Simulation Results

Use Case

Flexibility **Performance** **Cost**



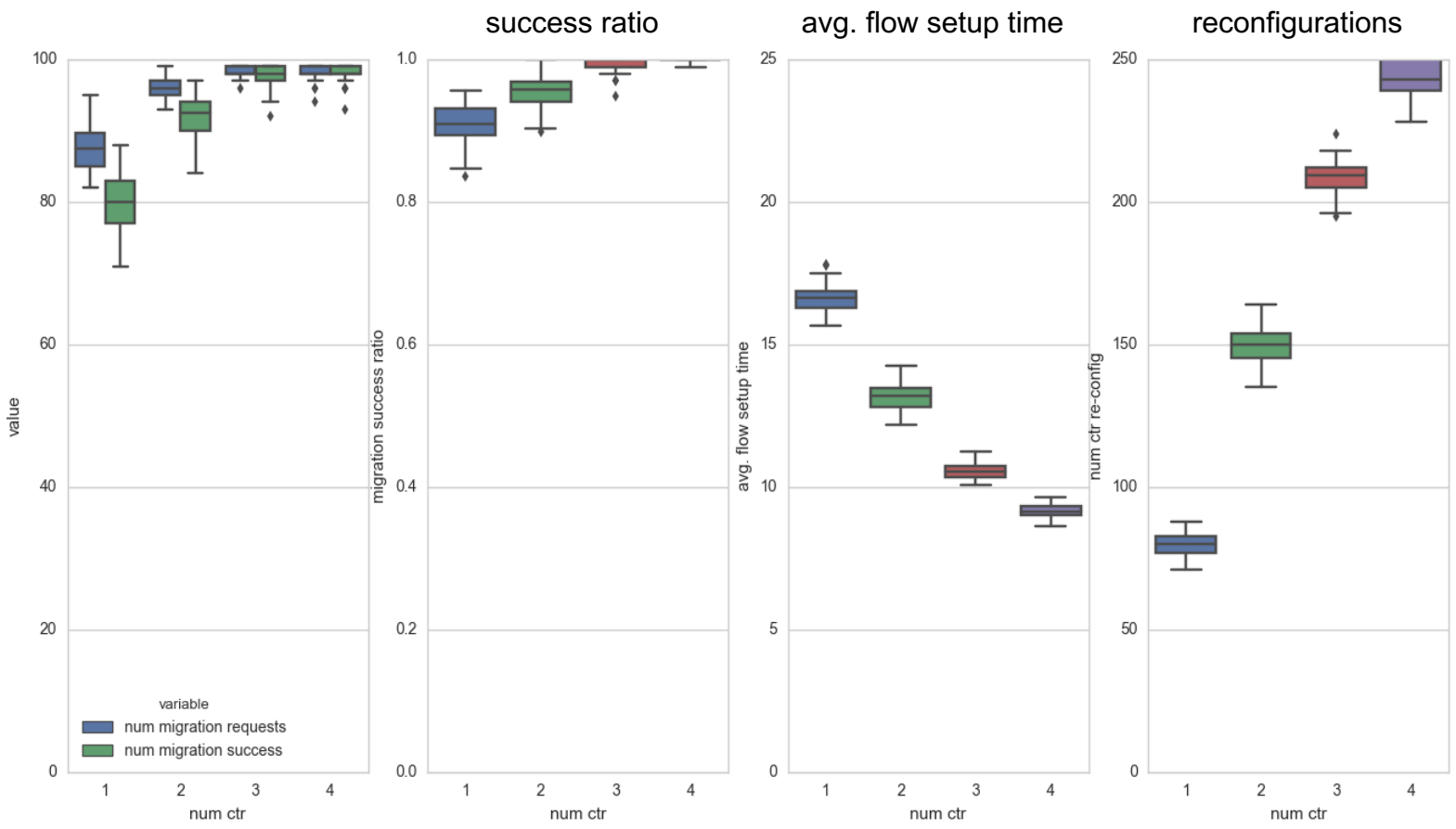
migration time threshold = 811 ms

T is moderate: more controllers → higher flexibility at higher cost

Simulation Results

Use Case

Flexibility **Performance** **Cost**



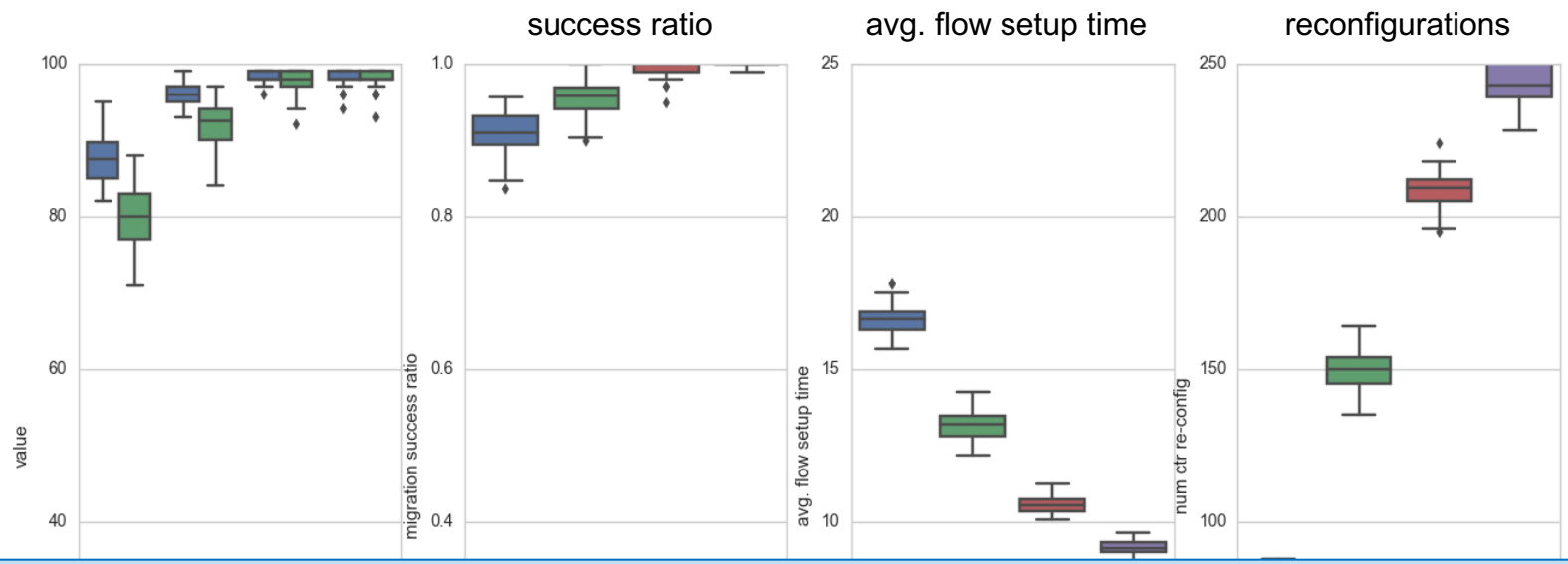
migration time threshold = 812 ms

T is moderate: more controllers → higher flexibility at higher cost

Interpretation

Use Case

Flexibility **Performance** **Cost**



- Some cases: 1 controller is more flexible (short T)
- T considerable for adaptation: more controllers → more flexible
- There is a cap in gain – cost is rising

migration time threshold = 812 ms